Climate Change Planning for Military Installations

Findings and Implications

October 2010

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Findings and Implications

October 2010

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List of Acronyms

AMOC	Atlantic Meridional Overturning Circulation
ARFORGEN	Army Force Generation
BASH	Bird Aircraft Strike Hazard
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
BRAC	Base Realignment and Closure
C	Centigrade
CAA	Clean Air Act
CC	Climate Change
CCRC	Climate Change Resource Center
CCSM	Community Climate System Model
CDC	Center for Disease Control
CERTS	Consortium for Electric Reliability Technology Solutions
CICE	Sea Ice Model
CONUS	Conterminous United States
COSIM	Climate Ocean and Sea Ice Modeling
CSREES	Cooperative State Research Education and Extension Service
CT	Contaminant Transport
CVI	Coastal Vulnerability Index
DHSVM	Distributed Hydrology Soil and Vegetation Model
DLQ	Deck Landing Qualifications
DMUU	Decision Making Under Uncertainty Centers/Collaborative Groups
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DR	Disaster Relief
EFETAC	Eastern Forest Environmental Threat Assessment Center
EPA	Environmental Protection Agency
ESA	Endangered Species Act
F	Fahrenheit
FS	Forest Service
FY	Fiscal Year
GAO	General Accountability Office
GCM	General Circulation Models
GHG	Greenhouse Gas
GPS	Global Positioning Satellite
HA	Humanitarian Assistance
IAMS	Information to Action to Mission Sustainability
IPCC	Intergovernmental Panel on Climate Change
JCS	Joint Chiefs of Staff
LANL	Los Alamos National Laboratory

LCLUC	Land Cover and Land Use Change
LLNL	Lawrence Livermore National Laboratory
MOC	Meridional Overturning Circulation
NASA	National Aeronautics and Space Administration
NAVFAC	Naval Facilities Engineering Command
NCAR	National Center for Atmospheric Research
NEPA	National Environmental Policy Act
NETAM	National Environmental Threat Assessment Maps
NGO	Non-Government Organization
NICCR	National Institute for Climatic Change Research
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSF	National Science Foundation
NWS	National Weather Service
ORNL	Oak Ridge National Laboratory
OSD	Office of the Secretary of Defense
OTSR	Optimum Track Ship Routing
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PM	Particulate Matter
PDI	Power Dissipation Index
POM	Program Objective Memorandum
PRV	Plant Replacement Value
RCW	Red Cockaded Woodpecker
REMG	Renewable Energy Micro Grid
RFP	Requests for Proposal
S&T	Science and Technology
SCAN	Soil Climate and Analysis Network
SERDP	Strategic Environmental Research and Development Program
SLOSH	Sea, Lake and Overland Surge from Hurricane
SLR	Sea Level Rise
TES	Threatened and Endangered Species
TRADOC	Training and Doctrine Command
TTP	Tactics Techniques and Procedures
UAV	Unmanned Aerial Vehicles
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USG	U.S. Government
USGS	U.S. Geological Survey
VFR	Visual Flight Rules
VIC	Variable Infiltration Capacity
WCRP	World Climate Research Programme
WWETAC	Western Wildland Environmental Threat Assessment Center

1 Introduction

The Department of Defense (DoD) recognizes climate change as an emerging issue with potential national security implications. As a result of these concerns, the DoD Strategic Environmental Research and Development Program (SERDP) is establishing a research and development program to address climate change effects on DoD installations and associated missions. To help establish the program, SERDP tasked Noblis to identify potential climate change effects on military installations and their missions and operations.

This report presents the findings portion of this study and discusses some implications on policy and practice. These findings were gathered during June 2009 through February 2010.

To accomplish the task, Noblis examined how climate change could affect all aspects of installation infrastructure and facility operations, environmental concerns, training and test ranges, missions, military training activities, and community and regional dependencies.. As part of the study, we visited two DoD installations within the United States in different environmental regions that are representative of various military missions and training requirements that have a diverse infrastructure and that may be susceptible to projected climate change impacts. We carried out eight specific tasks:

1. Identify current DoD climate change policies and activities that could be built upon to develop requirements for a research program.
2. Identify current DoD personnel perceptions of climate change as a threat to various mission areas at the installation level.
3. Review current climate change data and modeling information available for climate change analysis at the installation level as the basis for determining information and tools that need to be developed.
4. Develop a study framework for identifying and understanding climate change effects at installation level.
5. Visit two installations to determine how missions and duties might be affected by climate change and identify the tools and resources they have available for identifying and dealing with adverse impacts.
6. Develop a research strategy and portfolio to address climate change at installation level.
7. Develop an outline of a prototype system for assessing the effects of climate change on installations to identify adaptation and mitigation needs.
8. Develop a prototype documentation method.

The findings froom tasks 1-5 above are provided in this report. Section 2 is an overview of the study approach and the overall study theme "*Information to Action and Action to Sustainability.*" This theme recognizes that the principal threat of climate change to DoD, now and in the future, is to the Department's ability to sustain those resources needed for training, day-to-day operations, and assigned missions. Section 3 is a summary of study findings based on a literature search, interviews, and available documentation, followed by general discussion of these findings. Section 4 discusses the implications of these findings for future policies and practices. Five appendices are also included. Appendix A documents the current state of the practice for climate modeling and Appendix B provides a summary of projected changes in climate variables by region and time period. Appendix C presents a brief description of installation selection process for the study. Appendix D is a compilation of ongoing research by Federal agencies related to climate change impact assessment and adaptation planning. Appendix E presents selected findings from a General Accountability Office (GAO) report on climate change adaptation that are relevant to SERDP research and development activities.

2 Study Approach

Noblis adopted a study approach that sought to determine the "state of the practice" of climate change policy making and practice within DoD during the period of the investigation (June 2009 – February 2010) and to identify the office, if any, that had been assigned responsibility for this issue. (With regard to the latter, most organizations were waiting for policy guidance coming out of the 2010 Quadrennial Defense Review in progress during the SERDP study before taking any actions on their own.) We met with DoD personnel who had operational responsibility for activities most likely to be adversely affected by climate change-related impacts. As part of our approach, we engaged in scenario development to identify generally the types of effects that could occur, their potential severity, and potential effects on assigned missions. With this background, we were able to assess the utility of available climate change information needed for risk assessment and decision making within the framework of information to action and action to sustainability. The following sections provide additional detail on our study approach activities.

2.1 Identifying Current DoD Climate Change Activities and Perceptions

Noblis identified current DoD climate change policies and activities by reviewing available policy and guidance documents and interviewing stakeholders at all Component levels. The same approach was applied to the task of identifying current perceptions of climate change as a threat to operational and installation level mission areas. Policy and planning staff generally saw climate change in terms of its geopolitical implications and possible need for strategy changes. Training and operational staff were more focused on maintaining existing installation resources to meet current training needs and sustaining those resources to meet the needs of tomorrow.

2.2 Reviewing Climate Change Data and Model Projections

Noblis identified, reviewed, and analyzed available climate change data and modeling projections of climate change to 2100 in the conterminous United States (CONUS). The purpose was to determine what climate change information is currently available and applicable to climate change analysis at the installation level and to further identify where information and tools gap exists. A review of the current state of climate change modeling is provided in Appendix A as background for understanding the projected effects of changes in temperature, precipitation, sea level rise, and storms. A review of CONUS regional-scale climate change modeling is provided in Appendix B.

2.3 Developing a Framework for Installation Climate Change Planning

Noblis developed a framework for installation climate change planning based on an "Information-to-Action" concept. Figure 1 illustrates how climate change can potentially affect military missions. Countering these effects would require mitigation or lead to research and development. This is the basis for the Information-to-Action-to-Mission Sustainability (IAMS) approach.

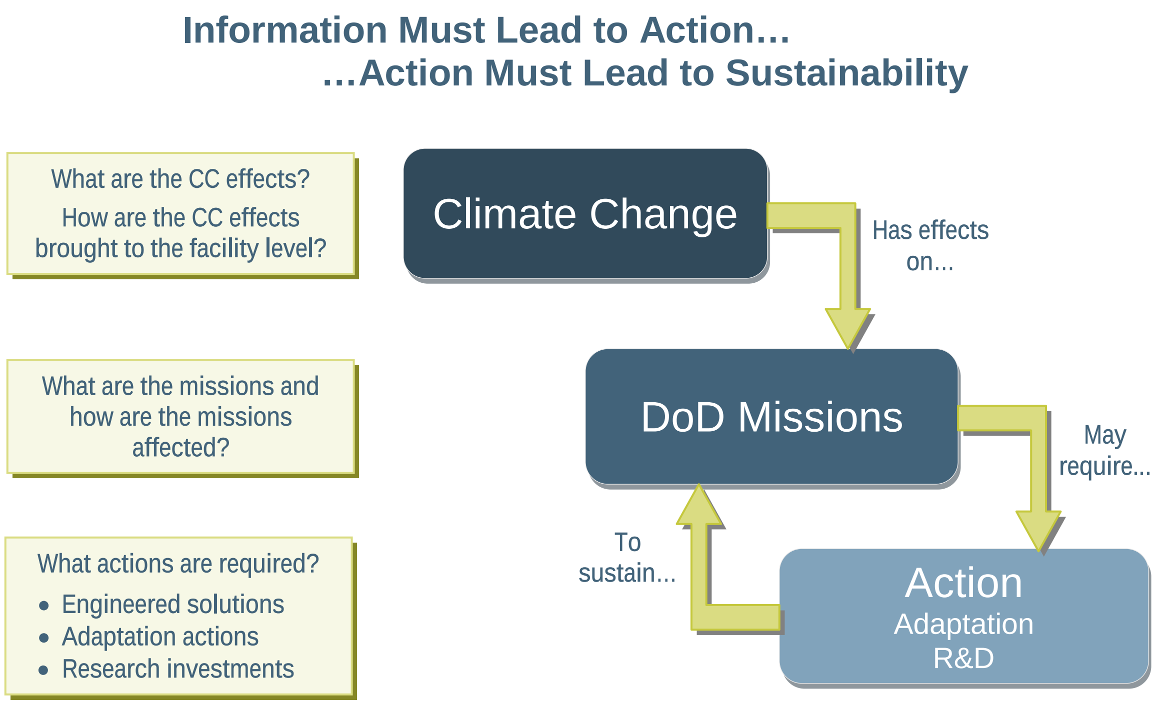

Figure 1. General Considerations Regarding Climate Change Effects on DoD Installations and Missions

Figure 2 presents in more detail the elements involved in an IAMS approach in which climate change information results in effective actions at the installation level. Key to this process is the collaborative efforts and the application of climate analytics. Climate analytics is a system that includes the organizations, processes, and expertise that must be brought to bear on information to conduct analysis and develop products considered actionable by installation managers. Actionable information is that which is applicable to manager responsibilities and missions and can be used to assess climate change effects at the installation level and determine the appropriate adaptation and mitigation actions.

Figure 3 outlines the "Information-to-Action" approach that was used to develop an operational framework for climate change planning at the installation level. Our framework for identifying research requirements considered current climate change information, climate change effects on facility missions and activities, and potential climate change effects on DoD operating forces and missions. We considered potential adaptation options and identified research areas that could contribute to solutions for current and future adaptation shortfalls. We noted value in identifying and cataloguing potential solutions for future use, refinement, and reference. Our reviews indicated that implementing adaptation measures will require facility commanders and organizational managers to consider proposed solutions and weigh these actions through a risk management approach. Adopted strategies must be not only cost-effective, but they also must be developed specifically for individual commands and facilities. This framework guided our information gathering, visits to military installations, analysis of data and information, and the findings that resulted.

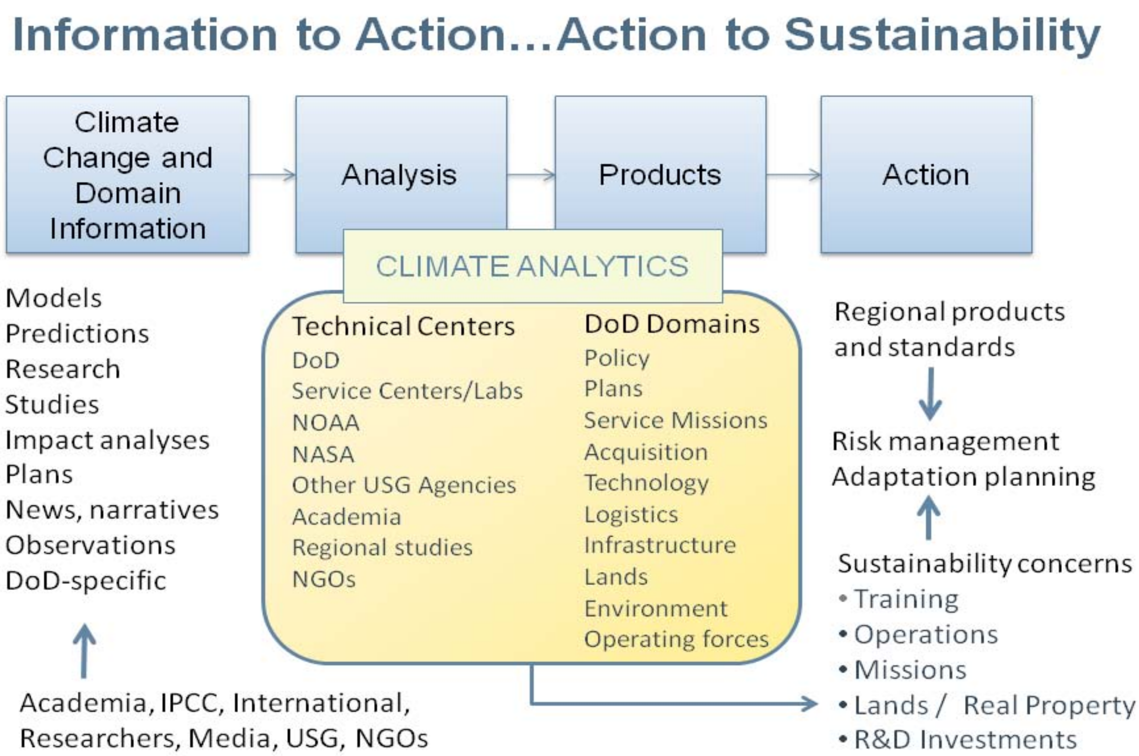

Figure 2. Elements of an Information–to–Action Framework

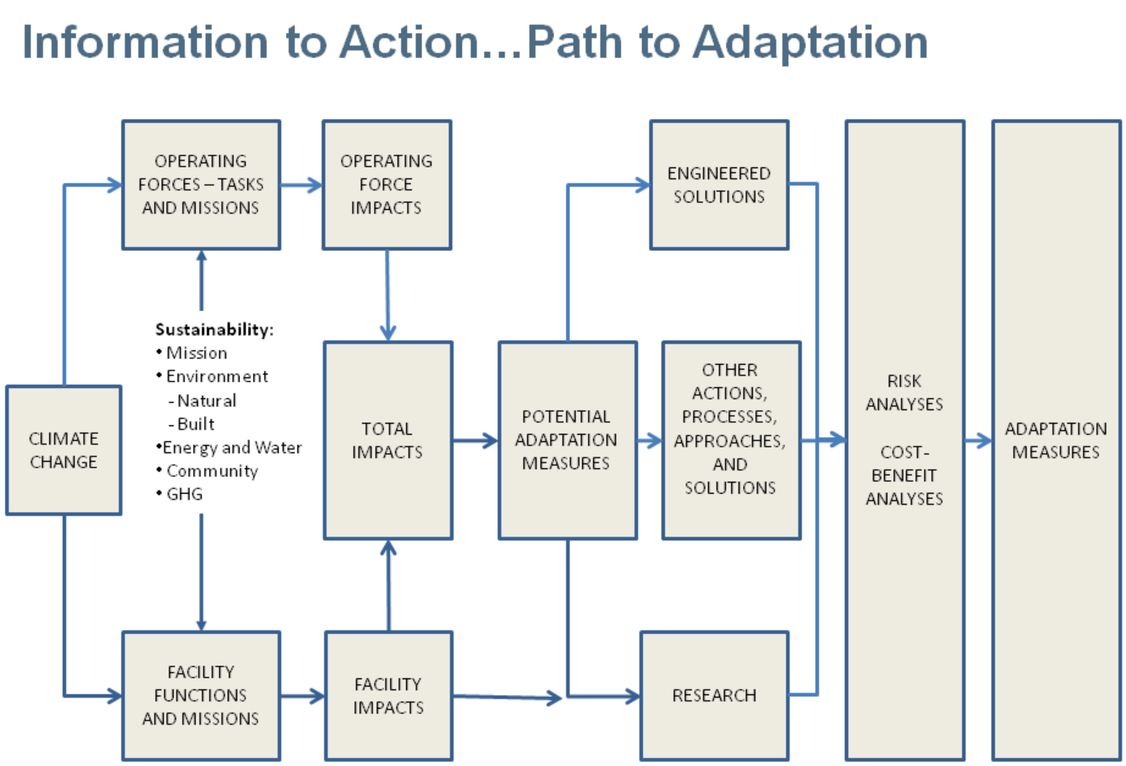

Figure 3. Framework for Assessing Climate Change Effects on Installations.

Climate change poses a potential risk to installation and mission sustainability and should be addressed as such (Figure 2). Noblis noted that there are relationships among climate adaptation and mitigation strategies, energy management, greenhouse gas (GHG) reduction, energy efficiency for built infrastructure, resource conservation, community interactions, and environmental stewardship all acting together at an installation. Climate change adaptation must consider relationships among these "stressors" because climate change effects will likely not be independent of other stresses on DoD facilities, operations, and budgets.

Sustainability is the capacity for continuous operations in the long-term coupled with resilience for maintaining operations in the case of short-term shocks and disturbances. For DoD installations, sustainability becomes the ability to carry out today's missions as well as those that may be assigned in the future. It also means the ability to maintain and enhance those natural resources and the built environment that are the sources of the capability to operate today as well as 100 or more years into the future. Climate change adaptation and mitigation should be considered in the broader installation mission sustainability framework.

2.4 Selecting and Visiting Installations

Noblis visited Ft. Benning, Georgia, and Naval Base Norfolk, Virginia, to identify how climate change could affect installation missions, infrastructure, and natural environments. These installations are representative of a wide range of military operations and types of infrastructure within CONUS and met many of the selection criteria listed in Appendix C with respect to geographic region (climate zone), facility land use, amount and types of infrastructure, coastal proximity, core missions, and military services supported.

During the installation visits, the Noblis team interviewed a broad cross-section of operating forces personnel and installation management and support staff. Interviews focused on specific interviewee functions and potential effects on their specific areas of responsibility. The interviews included military officers who were able to convey both operational and facility concerns related to weather and climate change. Interviews focused on unit and installation missions. Climate change scenarios were also used during the interviews.

2.4.1 Fort Benning, Georgia

Figure 4 shows the location of Fort Benning in west-central Georgia at Columbus, Georgia. Fort Benning is one of the largest U.S. Army installations with about 180,000 acres. It is a good example of large CONUS installations for training ground forces. The installation has extensive built infrastructure in cantonments and training areas and ranges. Large areas of natural landscapes must be maintained as training environments for infantry, armor, and aircraft operations and for firing small and large weapons. The installation must also recover and maintain threatened and endangered species and comply with air and water quality regulations. The installation could be subject to climate change that could affect installation operations, such as increases in extreme

Figure 4. Location of Ft. Benning in West-Central Georgia

heat events, changes in severe weather and occurrence of tropical cyclones, and alteration of the ecosystems and natural landscapes used for training.

Fort Benning will become the Maneuver Center of Excellence, encompassing the Infantry Center and School and the Armor Center and School. The Center of Excellence will be in place in 2011 when the Armor School is relocated from Fort Knox, Kentucky. The main installation mission is training. The installation also hosts a number of active-force tenant units, including a heavy brigade combat team, Ranger Regiment, combat sustainment support battalion, and combat support hospital. The installation is an Army power projection platform capable of deploying combat-ready forces by air, rail, and highway.

2.4.2 Naval Base Norfolk, Virginia

Naval Base Norfolk (Figure 5) is the largest naval installation in the United States with 4,300 acres and thus is representative of large bases that support active fleets. The base has very extensive shore-side and port infrastructure needed to support, deploy, and sustain surface and submarine vessels of a variety of classes. The base must also support and maintain important airfield operations for fixed-wing and rotary-wing aircraft. The base is located in a major metropolitan area and is dependent on the region for utilities and many services. Climate change effects that could affect the base include flooding from sea level rise and changes in severe weather and occurrence of tropical cyclones.

Naval Base Norfolk provides fleet support and facilities to ensure readiness for the U.S. Atlantic Fleet. The base is bounded on the north by Willoughby Bay, on the west by the confluence of the Elizabeth and James Rivers, and on the south and east by the city of Norfolk. Naval Base Norfolk consists of approximately 4000 buildings, 20 piers, and an airfield. The 20 piers range from 6 to 63 years old, with 11 piers at least 50 years old. All the pilings are reinforced in concrete, but are eroding at water level. Vessels reach the piers from the ocean via channels that are maintained at a minimum depth of 45 feet. The elevation of Naval Base Norfolk is 16 feet or less above sea level.

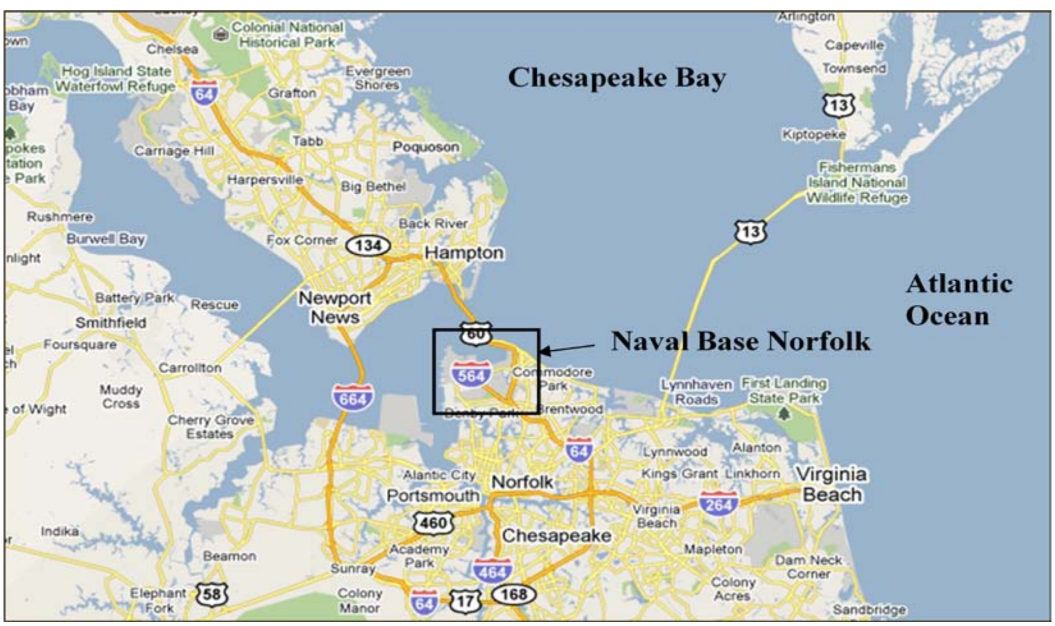

Figure 5. Location of Naval Base Norfolk in Norfolk, Virginia

3 Findings

This section presents findings from the analysis of information gathered during the study period (June 2009–February 2010), during installation visits, and from discussions with DoD military and civilian managers and supervisors. General findings are presented in Table 1 regarding perceptions of climate change, information sources and availability, and information utility followed by a discussion of these and other topics. Specific findings identified from interviews and from information obtained during the Noblis visits to Fort Benning, Georgia, and Naval Base Norfolk, Virginia, are presented in Tables 2 through 6 for the following categories: operating forces, natural resource management and conservation, environmental compliance, built environment, and organizational and administrative.

3.1 General Findings

Noblis reviewed available reports and documentation and interviewed personnel in the Office of the Secretary of Defense (OSD), Joint Chiefs of Staff (JCS), and the military services to determine the current perception of climate change as an issue and to identify any on-going or planned activities and projects about climate change effects on installations. We identified some general findings from analysis of the interviews and other relevant material (Table 1). These findings were remarkably consistent across all personnel interviewed. The sections that follow discuss these findings and other general observations and issues identified during the study.

3.1.1 Climate Change as an Issue

There was a general awareness of climate change among DoD personnel at all levels and some awareness of climate change as an issue that could possibly affect DoD installations at some point in the future. This awareness and knowledge was primarily from hearing and reading about the issue in the media. Climate change was not yet a subject of significant discussion among DoD managers. A few personnel stated that they had noted that climate change was starting to become a subject of sessions at conferences.

Personnel currently viewed climate change at this time as a strategic issue. Personnel were aware that climate change was an element of the on-going 2010 Quadrennial Defense Review and had some knowledge of the various studies that have been published about climate change as a national security issue. However, climate change was not considered an operational issue at the installation level at this time, but was acknowledged to be an issue that could possibly be important operationally at some unspecified time in the future.

3.1.2 Available Climate Change Information

General climate change information that personnel were aware of was not perceived as currently useful for analysis and planning at the installation level. There were several reasons for this perception. The information was considered too vague and general to be applicable or even relevant to the specific missions and activities for which personnel were responsible. The data were perceived to be at too large a scale, regional or multi-state, to be applicable at specific installations. Personnel stated that climate change information would be needed at a much finer scale to be considered useful for installation analysis. Personnel also did not know what climate change information was appropriate to use because of the differences in the results of different climate projections and scenarios.

Table 1. General Findings

Finding	Comment
Perceptions of Climate Change as a DoD Issue	
Climate change is currently perceived as a strategic issue, not a local operational issue	• Most personnel interviewed perceived climate change at this time as a strategic issue rather than an installation operational issue. • Personnel were generally aware of the several studies that have been published on climate change as a national security issue that could cause new military threats and possibly result in changes in strategic issues, missions, force structure and training requirements. • Personnel were also aware that the on-going Quadrennial Defense Review had climate change as part of the assessment for the first time. • These activities appeared to be much of the basis for reinforcing the perception of climate change as a strategic issue.
There is no perceived need to act at the installation at the current time	• Personnel interviewed did not perceive a need to act at the current time at the installation level regarding possible climate change effects. • The general view was that climate change is something "in the future" at the installation level and not relevant to current short-term planning horizons. • This perception may have been a result of personnel not having what they considered any useable climate change data. • However, personnel also stated that there is not currently any direction or guidance from higher levels that the issue is important at the installation level. • As a result, most personnel stated that they were focused on day-to-day activities and on short-term planning horizons and did not have time for something that was perceived to be well in the future. • It was stated that when guidance and policy "from the top" was received, they would then bring the issue into installation-level planning. • All personnel were aware of climate change and generally believed that it will need to be considered at installations. • Climate change knowledge came from hearing and reading about the issue in the media and from the inclusion of climate change as a subject in the on-going Quadrennial Defense Review. • Some also commented that climate change was beginning to be a subject at DoD environmental conferences. • This general awareness of climate change issues typically resulted in personnel believing that climate change effects would need to be evaluated for installation and other planning at some point in the future.
Perceptions of Climate Change Information and Data	
Facility managers do not have the information needed for climate change planning	• Commanders and managers did not believe that they had the necessary climate change information required for planning and analysis at the installation level. • Available climate change information is not perceived to be actionable at the installation level. • What general knowledge they did have was too vague to be used at an installation level. • Managers also stated that they did not know where to get climate change data even if they felt that they could use it. • They did not know which climate change information is "correct," which resulted from the perception that often climate change information that they did come in contact with was so variable.
Facility-specific and local-region-specific information is required for facility decisions and adaptation actions	• When asked what climate change information is needed, personnel stated that they needed to know what will happen, where it will happen, when it will happen, and the uncertainty associated with the information. • Required information must also be perceived to be usable at the installation or, at least, the local region scale. • The type of information provided must be relatable to the specific installation missions and activities that could be affected. • Personnel stated that they must be able to defend any decisions they would make that would use climate change information up the chain of command in review.

Finding	Comment
	• Installation personnel stated that they frequently use standards, specifications, and guidance documents in management and planning. They would expect information related to climate change effects to be incorporated into these documents for their reference. • Installation personnel responsible for design and construction of facilities stated that they use standards and specifications, such as the proper heating and cooling capacity for buildings that are provided to them in manuals that have been prepared by higher-level organizations such as NAVFAC and the US Army Corps of Engineers. These manuals currently have not included climate change in their formulation. • If specifications need to be changed to account for different future design conditions from climate change, personnel stated that the manuals would need to be changed by the higher-level organizations. • Local personnel have some flexibility if they have data that supports using a different standard, but they may have to defend using a different standard in approvals in the chain of command.
Using Climate Change Information	
Installations will be end users of information on climate change, not producers of this information	• Installation personnel stated that they have no expertise in climate change issues and would be unable to analyze climate change data if it were available. • They also stated that they do not know where to get climate change information even if they believed they could analyze it.
Installation personnel will expect useable climate change information to come from DoD and other federal technical support organizations	• Because they felt that they lacked appropriate climate change expertise, installation personnel stated that they would need to be provided with climate change information that is useful to them if they are to incorporate it into installation-level planning and management. • They stated they would expect technical organizations in DoD and other federal agencies to be the expert providers of climate change data to them. • They would also expect climate change information to be incorporated into standards, guidance, directives, and policy for their reference.
DoD science and technology organizations and processes have not yet evolved and adapted to address climate change issues	• Climate change adaptation is only just beginning to be addressed within DoD. • While the military service laboratories and facility support organizations have procedures and processes for dealing with the broad range of science and engineering challenges, there does not appear yet to be an integrated approach to providing best available analytical products to end-users for climate change. • Although climate change is a new science and technology (S&T) issue within DoD, S&T issues are not new to DoD. DoD is used to dealing with new S&T issues as they arise and can evolve and adapt the extensive S&T infrastructure and processes to incorporate new issues. • Noblis found that this has not yet occurred in DoD for climate change and no unified approach to climate change analysis has yet emerged.
Sources of Climate Change Information	
There is no current authoritative source of climate change information for DoD	• There is no DoD or military service focus for climate change information at the current time. • As noted in other findings, installations will expect there to be an authoritative technical source for climate change information for planning. • Noblis noted two partial exceptions to this. The Navy Task Force Climate Change has studied Arctic ice issues related to climate change and could be considered an authoritative source for this information. The US Army Corps of Engineers Civil Works has issued guidance on how to incorporate sea level rise into planning for coastal structures and engineered features.
DoD will need to bring ambiguous and disparate data in various formats to users	• Noblis noted during the review that climate change data and information is extensive and exists in a wide variety of formats. • This poses a challenge to DoD efforts to use information from multiple sources and make it actionable at the installation level for adaptation planning.

Finding	Comment
Working Across the Federal Government	
There is no current effective way to collaborate across civilian federal agencies with similar climate change issues and needs	• Many federal civilian agencies are facing similar climate change issues as DoD. • The agencies have missions, manage lands and waters, and have infrastructure and other physical assists that could be affected by climate change. • These agencies have also established initiatives to develop plans for climate change adaptation and mitigation. • Analytical capabilities to assess climate change and provide actionable findings and recommendations are spread across a number of research organizations, laboratories, federal agencies, and academia. • Noblis found no effective mechanisms currently in place that can help DoD collaborate and cooperate with civilian agencies and other organizations on climate change issues that are of common interest.
Some federal operational organization around climate change is emerging	• Noblis noted a few organizations that have been put in place or are planned that will focus on climate change in an operational way. • The Navy has established the Task Force Climate Change, which initially has focused exclusively on Arctic ice and strategic issues, but which could broaden its scope to other climate change issues and potential effects on the Navy and Navy installations. • The US Army Corps of Engineers Civil Works is standing up a Climate Change Adaptation Program at the Institute of Water Resources, which will serve as a focus for helping to deal with climate change as it may affect USACE responsibilities for water resources. • The Department of the Interior is establishing Regional Climate Centers that will provide information needed for land management decisions at the appropriate regional scale.

Personnel did not know where to obtain climate change information that would be considered authoritative and relevant to the installation level. Operating personnel felt that they were not qualified to develop their own climate change information and would need to be provided useable technical information by appropriate technical support organizations within the military services, DoD, or other federal agencies. Some support organizations mentioned were Naval Facilities Engineering Command (NAVFAC), U.S. Army Corps of Engineers (USACE), Army Environmental Command, and National Oceanic and Atmospheric Administration (NOAA).

3.1.3 Climate Change Guidance

Noblis did not identify any guidance regarding climate change at the installation level. Operating personnel stated that they were looking for “guidance from the top” before they considered climate change an important issue. Personnel were not aware of any climate change guidance or focal point for climate change within the military services or DoD. Guidance was needed for personnel to know how to incorporate climate change effectively into planning and analysis. However, a few managers stated that they were taking some actions regarding climate change on their own initiative without guidance but could not proceed very far until official guidance was available.

3.1.4 Planning Horizons

Personnel generally did not consider climate change to be a relevant issue within the planning horizons they typically use in their mission areas. Planning horizons varied somewhat depending on the responsibilities of personnel, but were generally short-term to mid-term. Short-term planning horizons were generally ten years or less and many personnel focused primarily on the 6-year Program Objective Memorandum (POM) cycle. Personnel responsible for buildings and similar infrastructure used a mid-term 20-40 year life cycle and stated that the official life-cycle period for infrastructure is 67 years. Range and training area managers generally used a 10-20 year planning horizon, although one study identified is using a 50-year horizon. Personnel did not consider climate change relevant to these time periods because climate change was perceived as something that happens at time scales longer than current planning cycles.

3.1.5 Climate Change Activities and Projects

Noblis identified only a few on-going or planned DoD climate change activities during the study period. Because of the perceptions described in previous report sections and the current lack of guidance, most organizations had not undertaken any projects or activities regarding climate change effects on installations. Activities that Noblis identified are summarized below.

The OSD Office of Readiness Policy and Programs will conduct a study of the potential effects of climate change on military training. The effort will support the Sustainable Range Integrated Program Team. Activities include identifying effects on training activities and facilities, identifying possible preventive measures, holding a workshop on this issue, and identifying experts who can assist OSD with this issue.

The USACE Office of Civil Works has established task forces and organizations to deal with sea level rise and increased storminess specifically, and climate change effects in general, on USACE civil works responsibilities and infrastructure. Task forces are investigating sea level rise and effects on infrastructure and engineering requirements, environmental impacts, guidance, and policy. USACE and the Department of the Interior's Bureau of Reclamation have studied climate change effects on water resources and the implications on USACE water management and flood control infrastructure and responsibilities. The USACE has proposed establishing a Climate Change Adaptation Program at the Institute for Water Resources. The USACE Environmental Laboratory has designated a person as the research and development lead for climate change. The USACE has issued revised guidance for incorporating sea level rise into planning for civil works projects and is preparing a supporting Engineer Technical Letter.

Noblis also conducted an overview survey of civilian agency climate change research related to climate change impact assessment and adaptation planning. The survey was based on readily available information. A variety of types of projects and areas of research were noted across a number of federal agencies. An overview of the information that Noblis identified is provided in Appendix D.

3.1.6 Climate Change Analytical Capabilities within DoD

Noblis did not find an authoritative DoD source of climate change data or analysis during our research and interactions with DoD organizations, nor did we identify a program that would provide efficient, effective, authoritative support to DoD and its components for long-term support in the area of "climate analytics." However, various elements of DoD have organization-specific levels of science-and-technology-based support for engineering, laboratory research, and access to outside research results that could be the basis for establishing a climate change analysis and assessment capability.

3.2 Installation Level Findings

Findings from the installation visits are presented in Tables 2 through 6. These issues are discussed for Fort Benning in Section 3.2.1 and for Naval Base Norfolk in Section 3.2.2.

Table 2. Findings for Operating Forces

Finding	Comment
Ground Forces	
Extreme weather and meteorology can affect or modify training.	Planners and trainers are not aware of specific overall changes in climate that would directly affect installation or unit training or operations. Nevertheless, extreme weather and meteorology had or can affect and require short-term modification of training and operations to ensure safety of soldiers and equipment. Specific examples of extreme meteorological conditions cited that had affected military training and operations included: • Extremes of heat or cold causing unsafe conditions for training • Ice or sleet causing unsafe conditions for mountain training • Drought that increased the possibility of fires on training area and ranges • Floods/soil saturation causing unsafe river operation conditions • Cloud cover causing unsafe flying conditions or noise propagation or laser safety concerns • Lightning endangering soldiers in the open • Tornadoes and hurricanes causing loss of power and damage to facilities and equipment
Trainers consider extreme meteorological conditions as normal adverse weather events and not indications of overall changes in the climate.	Installation and units normally plan for and practice measures to mitigate the effects of weather and minimize immediate impacts on training and operations as an integral part of realistic training and a reality of real world operations.
Safety or regulatory concerns were the key considerations in modifying or temporarily stopping training or operations.	Installations and range operations staff routinely monitor and provide warnings of adverse weather conditions to allow tenants and units to adapt work and training schedules and activities to minimize the potential impact of predicted adverse weather.
Training and operations that might be delayed or rescheduled because of weather-related lack of range availability or required support include: aviation, river, airborne, mountain, and some firing operations.	Scheduling “gated” training requirements such as zeroing before qualifying and qualifying before maneuver training events is a challenge. If these key readiness training activities cannot be completed, they may have to be postponed and conducted later at home station or at a contingency deployment location.
Army Force Generation (ARFORGEN) rotation of operational units and personnel overseas has significantly intensified installation training and operations.	Deconflicting range training requirements is a challenge, and as training demands grow, installations and units lose flexibility in scheduling in response to adverse weather conditions.
Increases over time in the magnitude and/or frequency of extreme weather conditions due to potential climate change could affect the quality of installation living and working environments.	Weather and ecological effects that could affect training and operations included: • Flooding that restricts river crossing operations. • Wet soil and subsoil causing increased maneuver damage and sediment run off into impeded waterways and potentially limiting heavy vehicle maneuver. • Lightning that may endanger soldiers and equipment and temporarily halt field training. • Overcast skies/cloud cover that can refract and amplify the levels and increase ranges of vehicles and firing noise, lasers range and targeting devices and potentially limit specific training activities. • TES habitat management that may limit heavy vehicle training in certain areas and during certain species mating times. • BRAC and range construction required mitigation monitoring plans and goals.

Finding	Comment
Over time, weather effects could affect installation compliance with regulatory requirements such as the Clean Air Act, Threatened and Endangered Species, impeded waterways, and wetlands management.	Installations and units commit significant effort to comply with various regulatory requirements to include compliance with long-term ecosystem and environmental quality management goals. Inability to meet Federal and state regulatory guidelines and requirements could adversely affect operating permits and limit land use required for training and operations.
BRAC-related increases in training frequency, density, and load will increase potential for adverse weather impacts on training ranges and activities.	Examples of weather and ecological effects that could adversely impact increased heavy vehicle training include: • Flooding that restricts river crossing operations. • Wet soil and subsoil causing increased maneuver damage and sediment run off into impeded waterways and potentially limiting heavy vehicle maneuver. • Lightning that may endanger soldiers and equipment and temporarily halt field training. • Overcast skies/cloud cover that can refract and amplify the levels and increase ranges of vehicles and firing noise, lasers range and targeting devices and potentially limit specific training activities. • TES habitat management that may limit heavy vehicle training in certain areas and during certain species mating times.
Specific capabilities of new weapons systems; munitions; and tactics, techniques and procedures (TTP) of future combat units and potential impacts on training ranges and environments must be characterized including the impacts of long term meteorological conditions and changes.	Modernization of military ground maneuver combat forces and weapon systems will significantly increase the range, speed and lethality of future combat systems and units. Examples of specific future concerns include: • Unknown performance and range impacts of new weapons systems and munitions causing uncertain range safety requirements. • Increased use of flat, steel targets for immediate training feedback causing fragmented munitions residue versus whole lead bullets to be exposed to weather/environment. • Increased use of fire and forget wire guided missiles versus direct fire tanks rounds. • Potential use of thermobaric warheads. • Increased use of small UAVs primarily VFR and adverse weather creating air space control challenges and need to restrict airspace.
To effectively sustain ground force training and operations, best management practices to mitigate adverse effects of future combat systems and any potential climatic impacts must be "proactively" indentified, evaluated, and implemented.	As military ground maneuver combat forces and weapon systems are modernized, potential specific impacts on ranges and environment must be identified and best management practices identified, demonstrated and documented and made available to installation and units as lessons learned.
Installation and unit trainers need information, planning tools, policy guidance, and resources to understand, plan for and address any potential long-term impacts of climate change effects on training and operations.	The Training Risk Management Process works well, but unknown, unintended secondary impacts are a concern to trainers and operators who are too involved in working day-to-day issues to research and plan for long term issues.

Finding	Comment
Naval Forces and Facilities	
Vessel maintenance and preservation will be adversely affected by increased temperature, precipitation, and weather effects.	Additional costs and manpower will be required to sustain material readiness standards.
The effects of intense weather significantly affect operations (precipitation, heavy winds, and high seas).	Personnel and ship safety can be affected. Sea state limitations already affect some ship classes and design limitations are approached under some conditions. Ship operational tempo and underway training will be affected by extreme weather conditions expected under some climate change scenarios.
Limitations in allowable underway training days resulting from extreme weather conditions will affect ship and crew certifications.	Ships are limited in underway training by operational tempo and fuel concerns. Loss of training time will affect readiness, and margins for loss of training time are small.
Naval vessels can be expected to have increased operational tempo to support Disaster Relief (DR) and Humanitarian Assistance (HA) missions.	Climate change projections indicate that coastal inundation and associated dislocation and migration of personnel will necessitate DR and HA missions. Additional preparations and tailored force structure concerns may be appropriate
Climate change effects and sea level rise are expected to affect supporting land-based and open-ocean infrastructure.	Effects on communication facilities, ranges, test, and maintenance facilities will need to be considered. This issue requires further specific analyses. While inundation of island-based facilities is an obvious consideration, more subtle effects and secondary considerations for continuity of supporting operations should be considered
Ocean acoustic changes resulting from higher water temperatures, changes in salinity, and relocation of ocean currents could have significant effects on sonar capabilities and operation.	This is an area for further analysis and impact assessment.
Higher water temperatures affect equipment performance.	Propulsion capability may be limited by condenser performance. Higher ambient temperatures will require additional air conditioning capacity and auxiliary power. Ship design and performance issues require further review and analysis.
Ship condenser performance may be affected by marine fouling associated with higher seawater temperature and changes in marine organisms of interest.	Potential area for analysis.
The effectiveness of in-port training (ships alongside the pier) will be of increasing concern due to fuel economy, operational tempo limitations, and vessel availability for deployed operations.	In-port training requires continuity of shore power and other services. Shore power capacity may be a limiting factor in supporting alongside training. Safety and facility concerns prevent effective full-scale training involving sonar, air operations, and weapon systems.
Climate change may affect coastal and harbor topography, bathymetry, current conditions, and salinity.	Maintaining adequate nautical charts and information concerning operating areas and ports will be increasingly challenging. Salinity is an important factor to consider when designing and specifying in-water equipment and facilities in ports because of the effects of salinity on operation and maintenance.

Finding	Comment
As sea level rises, pier and berthing adequacy for ships may become increasingly difficult to maintain.	Pier design, local water depth changes due to sedimentation, adequacy of shore utilities, and channel depth will be of increasing concern. This will be of particular concern for berthing in foreign ports where infrastructure adaptation is less predictable.
Shore-based maintenance facility capacity may be affected by climate change, especially sea level rise.	Maintaining adequate dry dock and related shore infrastructure (cranes, roadways, rail) may affect long-term maintenance.
Changes in beach and near-shore environments can affect training.	Near-shore and beach environments are important training environments for amphibious operations and for small boat operations.
Aviation	
Flying conditions can alter or cancel training.	Some conditions that can alter or cancel training are unsafe flying conditions and visibility. Climate change that affects flying conditions at a location could affect operational tempo and the ability to complete training requirements during a training rotation event for aviation units and for the ground forces that the aviation assets support. UAVs are greatly increasing in importance as elements of operating forces. Flying conditions that affect UAV operations and training events are therefore also increasing in importance.
Increased temperature, precipitation, and humidity will have adverse effects on aircraft preservation and equipment maintainability.	Additional costs associated with maintenance and repair. The rate of electronic equipment failures increases in high-heat environments.
Increased ambient temperature will have long-term effects on aircraft performance.	Performance and load capacity will be degraded under certain temperature change scenarios. As temperature rises, aircraft lift capacity will be reduced. This will result in reduced endurance, range, and lift capacity because of the need to reduce fuel load or reduce cargo load to compensate for reduced lift. While these effects may be small on individual missions, long term aggregate effects will need to be considered in overall fuel budgets and aircraft mission capabilities. The incremental nature of these concerns is not likely to cause design concerns, but should be considered in fuel use and operations in high temperature environments.
Additional lift capacity may be required to support DR/HA missions that are likely as a result of climate change effects.	Airlift capacity is an important element for rapid response in disaster relief and humanitarian assistance missions. If these types of DoD missions increase as a result of global climate change globally, then any climate change effects that reduce airlift capacity would be of concern.
Hanger capacity may limit the number of aircraft that can be protected from the environment.	This is a particular concern in regions exposed to sea air and severe weather effects. Long-term plans for aircraft maintenance and refurbishment cycles may need to consider regional climate effects and areas of operation.
Ground support equipment (lights, radars, antennae, arresting gear, handling gear) will be subject to harsher environmental conditions.	Additional maintenance costs and shortened life cycles may result from climate change effects (increased temperature, humidity, precipitation, salt-air exposure, and inundation). Increased maintenance and shorter replacement cycles may be necessary.
Bird Aircraft Strike Hazard (BASH) may result from changing wildlife migration patterns and area presence.	Significant area of concern connected to ecological changes and wildlife migration patterns. Local ecological changes may contribute to additional hazards and methods that are effective in hazard reduction.
Aircraft fuel formulation and requirements for engine efficiency may be subject to carbon reduction measures and GHG controls.	Unknown and evolving area subject to policy measures that could be affected by climate change.

Table 3. Findings for Environmental Management and Conservation

Finding	Comment
Current Management Issues and Practices	
Sustaining training on terrestrial landscapes is principal land management objective.	Managers consistently stated that supporting and sustaining the landscapes for training is their main mission. Managers work with trainers and units to maintain training areas as effective training environments. Managers must manage the landscapes in a sustainable way while also maintaining compliance with environmental regulations and requirements.
Sustaining desired types of training environments is an important management objective.	Training requires different types of landscapes, such as woodlands, grasslands, and deserts. Installation managers must maintain training areas as the desired type of landscape for that location.
Near-shore and beach environment is an important type of training environment.	This type of environment was mentioned consistently as important to training of Navy personnel for amphibious operations and for small boat training.
Effective threatened and endangered species management is crucial to sustaining access to training areas.	Managers consistently stated that effective threatened and endangered species management was a crucial part of their mission and frequently one of their biggest challenges in maximizing training area availability.
Prescribed burning is an important landscape and ecosystem management tool.	Prescribed burning is frequently used to maintain natural ecosystems and habitats, maintain open training areas, control fuel loads in training areas, and reduce the risk from fires ignited during training activities from weapons firing and pyrotechnics and other causes. Fire breaks are used in training areas to control prescribed burns and as protection when unwanted fires are ignited during training events. Prescribed burns must meet requirements for managing smoke and comply with air quality requirements.
Threat of training-caused wildfire can affect ability to train or alter training activities.	When the fire danger rating is high, training can be affected because of the threat of igniting unwanted fires. Weapons firing and use of pyrotechnics and incendiary devices may not be allowed. Training could be cancelled if the danger of fire is great enough.
Effective erosion control is very important to sustaining training area availability.	Managers stated that controlling erosion is a major management activity. If erosion is not adequately controlled, it can quickly make training areas unusable for vehicles because of gullies. Managers stated that unit commanders will complain if erosion gullies interfere with training. Erosion problems can also increase the time required for a training area to recover after a training event, which can affect training rotation tempo.
Effective and timely recovery of land from training-event damage is important to sustaining training area availability and maximizing training rotation tempo.	Managers stated that an important part of their job is to repair and recover training areas after training rotations to sustain the training tempo needed. Conditions such as drought or excessive wetness can make timely repair and recovery difficult and keep training areas unusable for longer periods.

Finding	Comment
Climate Change Considerations	
Climate change is not currently a consideration in management and planning.	Managers stated that keeping up with day-to-day requirements takes most of their time. Climate change is not yet a consideration in current management activities. Higher level commanders and managers have not yet stated that climate change is an important issue.
There is no guidance for including climate change in planning and management.	Managers stated that they would need guidance if they were to begin to consider climate change in planning and management. Managers state that currently there is no guidance known to them.
Managers would look to DoD or other technical organizations to provide climate change information to use in management and planning.	Managers consistently stated that they did not have the expertise to identify, analyze, and use climate change information. They would expect support and technical organizations within their military service, DoD, or other appropriate federal agencies to have such expertise and to supply them with appropriate information.
Climate change information provided must be authoritative.	Managers stated that they considered the climate change data that they were aware of was so variable that they would not know which information to use. They would want any climate change information provided to them to come from what they would consider to be an authoritative source.
Potential Climate Change Effects of Concern	
Installation ecosystems and habitats could change causing changes to or the loss of the desired type of training landscapes and environments at that installation.	When presented with a scenario of possible climate change for their installation, managers felt that it could possibly cause the installation ecosystems and habitats to change to adapt to the new climatic conditions. Installation training missions could be significantly affected if the installation ecosystems changed enough. An example given was that drier conditions could cause woodland training environment to change to a savannah environment.
Beach and coastal training environments could be lost from sea level rise.	Managers stated that if sea level rise significantly altered or caused the loss of beach and coastal environments, important training could be altered or eliminated.
Natural burning regimes could change.	Managers were concerned if prescribed burning regimes changed. More frequent burning could reduce training area availability and could cause problems with meeting air quality standards.
Threat of unintended wildfires caused by training activities could increase.	Managers were concerned that drier environments or more or longer periods of drought could increase the number of high fire danger days, which could affect training by increasing the number of times that training must be adjusted.
Prescribed burning programs could become more difficult to implement and manage.	Because of the importance of prescribed burning as a management tool, drier conditions or more or longer periods of drought were mentioned as situations that could complicate burning programs. Threats of concern were more difficulty in controlling prescribed burns and the need to burn more frequently, which could reduce training area availability.
Damage recovery of training land could take longer.	Any change that increased the time needed for training areas to recover from training damage was considered a concern by managers.
Erosion control could become more difficult.	Conditions that required more intense erosion management were considered to be of concern. Examples cited were more intense rainfall events or drier conditions.
Threatened and endangered species management and could become more difficult and adversely affect training capabilities and rotations.	Manager felt that changes in ecosystems and habitats from climate change would alter the conditions for recovering and maintaining threatened and endangered species. If these changes were negative for recovery, it could adversely affect the ability to maintain training area availability.

Table 4. Findings for Environmental Compliance

Finding	Comment
Climate change effects on ecosystems and habitats could create conflict with Endangered Species Act compliance.	Requirements for Endangered Species Act species recovery and maintenance are established using historical and current conditions. Installation ecosystems and habitat changes from climate change could increase the difficulty in meeting the installation recovery and maintenance requirements. However, the habitat changes that could occur from climate change would not be the result of anything done by the installation and would be beyond the control of installation managers. There is no policy or provision to account for climate change within the Endangered Species Act regulations that would allow adjusting the recovery and maintenance requirements to a changing ecosystem and habitat.
Wetland management issues could be exacerbated by climate change.	Climate change could alter the ability to mitigate wetland losses on-post if wetlands are affected by training needs, forcing an installation to use more off-post mitigation measures.
Climate change could affect Clean Air Act compliance for ozone.	High-heat days can contribute to ozone formation. Higher air temperature and more high-heat days could result in violations of ambient air quality standards.
Climate change could affect Clean Air Act compliance for particulates.	Controlling dust generated during training activities is an important management activity to assure compliance with ambient air quality standards for particulates and for visibility in Class I areas. Drier climate conditions or an increase in the number or length of droughts could result in more dust being generated during training activities, requiring more extensive dust control measures and making it more difficult to meet compliance requirements.
Off-installation noise issues could be affected by changed atmospheric characteristics from climate change.	Noise from installation training activities such as firing of weapons and low-level flying within installation boundaries can cause complaints from citizens in surrounding areas. Atmospheric conditions such as inversions can exacerbate noise propagation off of the installation. Noise complaints, if extensive and persistent, can result in modifying noise-generating activities, such as restrictions on time of day when weapons can be fired. Climate change that resulted in more frequent occurrence of conditions of off-installation noise propagation could have a significant effect on training.

Table 5. Findings for Built Environment

Finding	Comment
Buildings and installation infrastructure are older and either in need of repair or replacement.	Limited maintenance budgets are inadequate to provide required building repairs leading to increased susceptibility to climate change, especially regarding the ability to withstand severe storm damage.
Installations in urban areas have limited opportunities for relocating facilities or for adding new facilities.	Older installations in urban areas may have limited options for siting new construction either due to encroachment or because buildable sites are currently in use. Relocating facilities to minimize increased flooding risk may be problematic.
Buildings and other structures that are site-specific or that cannot be relocated will have to have their elevations raised above projected flood heights.	Other measures may include use of watertight doors and windows to protect critical equipment and use of submersible pumps.
Utilities and infrastructure are built to standards that reflect historic climate conditions.	New construction may be expected to have a serviceable life that extends late into this century. Buildings and supporting infrastructure should be constructed to revised standards that account for changing climatic conditions.

Finding	Comment
Storm water collection and treatment systems should be resized to reflect increased storm intensity peak discharge rates.	Weather patterns in many areas may change such that rainfall comes in less frequent but more intense events. Storm water systems are typically sized according to the historic 5-minute and 1-hour peak flows.
Roads and rail lines located in low lying coastal areas may need to be relocated because of flooding, either coastal or inland, and to increased erosion due to storm. surge.	Increased flooding may be expected in some areas due to increasing sea levels and storm surge, more intense rainfall patterns, or other factors. Mud slides resulting from intense rainfall or protracted storm events may also have adverse effects on transportation assets.
Increasing sea levels may decrease the hydraulic capacities of wastewater treatment plants to pass peak flows.	Flood gates or other engineering solutions may be needed to insure that rising sea levels do not backflow into treatment plants and outfalls.
Water conservation measures will be necessary in areas subject to drought.	Water resources in many parts of the country are approaching their carrying capacity. Additional regional growth, increasing annual average temperatures and changing precipitation patterns will further strain available water resources.
Increasing sea levels may threaten fresh water supplies.	Subsurface aquifers and surface waters may be contaminated from saltwater intrusion either caused by rising sea levels and/or excessive drawdown.
New construction must be more energy efficient and reduce both building and heating loads.	Increased demand for electricity will occur both due to increased annual average temperatures and to population growth straining both generation and transmission capacities. Equipment failure may become more frequent due to these increased demands and peak temperatures – the latter effecting the performance of generating and distribution systems.
Many of the climate change impacts on the built environment can be remedied, at least temporarily, through engineered solutions, but these solutions need to be based on "good" estimates of these impacts and their consequences.	Engineering solutions can be applied to many of the problems listed above and thus provide some degree of risk reduction; however, these solutions require good estimates of both the magnitude of climate change, the timeframe within which this change will occur and frequency of occurrence of climate change related events such as droughts and severe storms.

Table 6. Findings for Organizational and Administrative Activities

Finding	Comment
Climate change effects on installations need to be considered as another element within the broader context of installation sustainability	Climate change can be a stressor that affects installation training, mission, and infrastructure in the same way as other stressors and issues such as encroachment, energy conservation, and greenhouse gas emission reduction. Therefore, climate change should be brought into the larger framework of installation sustainability already in place in the military services.

3.2.1 Site Visit to Fort Benning, Georgia

A Noblis team visited Fort Benning, Georgia, from 26 to 29 October 2009. Noblis interviewed personnel responsible for operating forces missions and for facility missions and activities.

Climate change was not found to be an issue included in planning at Fort Benning. Personnel were almost entirely focused on day-to-day management issues and stated that they did not generally have time for longer-term issues. Personnel were also planning for the many issues and challenges associated with preparing for the movement of the Armor School to Fort Benning by 2011.

3.2.1.1 Operating Forces

Personnel interviewed were responsible for a variety of activities associated with the training of operating forces. The primary mission focus currently at Fort Benning is on infantry training. Noblis interviewed personnel responsible for unit training on Fort Benning lands and waters and personnel responsible for scheduling and maintaining training areas and ranges. Noblis also interviewed personnel planning for the move of the Armor School from Fort Knox to Fort Benning in 2011.

Sustainment of Readiness Training and Mission Operations

Unit trainers and operators generally stated that their mission objectives were to plan for and conduct effective scheduled training and operations while keeping soldiers safe, protecting the threatened and endangered species (TES), and sustaining habitat in support of realistic and challenging training. Installation specific trainers and operators generally cited the need to comply with environmental or ecological regulations and management guidelines as potential drivers for adaptive management of installation training or operations. Sustainment planning is addressed in time frames of 5 years, 25 years, and beyond. Ultimately, the stated installation goal is to sustain effective installation and readiness training and mission operations by anticipating and mitigating any potential climate-related effects.

Climate Change Effects

None of the individuals interviewed indicated that they were aware of any specific overall change in climate that had directly impacted installation or unit training or operations. Nevertheless, each interviewee stated that occasions of extreme weather and meteorology had or could impact and require short-term modification of training and operations to ensure safety of soldiers and equipment. Specific examples of extreme meteorological conditions cited that had impacted military training and operations included:

- Extremes of heat or cold cause unsafe conditions for training.
- Ice or sleet storms cause unsafe conditions for mountain training.
- Drought causes increased possibility of range fires.
- Floods/soil saturation causes unsafe river operation conditions.
- Cloud cover causes unsafe flying conditions or noise or laser safety concerns.
- Lightning endangers soldiers in the open.
- Tornadoes and hurricanes cause loss of power and damage to facilities and equipment.

Extreme meteorological conditions were considered normal adverse weather events as opposed to indications of overall changes in the climate. Moreover, weather and climate are considered essential conditions of realistic training. As such, the installation and units normally planned for and practiced measures to mitigate the effects of weather and minimize immediate impacts on training and operations. Decisions to adapt operations to minimize the impacts of adverse weather are considered an integral part of realistic training and a reality of real-world operations.

Safety or regulatory concerns were the key considerations in modifying or temporarily stopping training or operations. The installation and range operations staff routinely monitored and provided warnings of adverse weather conditions to allow tenants and units to adapt work and training schedules and activities to minimize the potential impact of predicted adverse weather.

Training and Operational Demand and Effects

The above notwithstanding, the training schedule at Fort Benning is intense. Fort Benning is a Tier I Army installation that conducts an average of 114 training events per day (half are live-fire and ten are considered hazardous) on 70 ranges. Any disruption of training due to adverse weather can affect training and operations at a number of key force readiness and generation installations such as Fort Benning. Institutional and unit field training and range activities are scheduled continuously at many of these key installations, and any lack of availability of training facilities and ranges could result in key readiness activities not being conducted during the times allotted to classes. This could be particularly challenging for National Guard and Reserve units that typically have a very limited total of 37 days per year that includes only two weeks in the summer for key readiness qualification and/or certification activities conducted at ranges and facilities not available at home station.

Army Force Generation (ARFORGEN) rotation of operational units and personnel overseas has significantly intensified installation training demands. Normal training tempo is 242 days per year, but Fort Benning now schedules training activities for 350 days per year. The heaviest training loads are in the spring through late summer. Scheduling “gated” training requirements, such as zeroing in weapons before qualifying and qualifying before maneuver training events, are challenges. Deconflicting such range training requirements is a challenge, and as training demands grow, the installation and units lose flexibility in scheduling.

Training and operations activities identified during the interviews that might be impacted (delayed or rescheduled) by weather-related lack of range availability or required support include aviation, river, airborne, mountain and some firing operations. If these key readiness training activities cannot be completed, they may have to be conducted later at home station or at a contingency deployment location.

Increases over time in the magnitude and/or frequency of extreme weather conditions due to climate change would also impact the quality of installation living and working environments. The installation commits significant effort to comply with various regulatory requirements that include compliance with long-term ecosystem management and monitoring goals.

Future and Long-Term Effects

The Army is relocating the Armor School from Fort Knox, Kentucky, to Fort Benning and creating the US Army Training and Doctrine Command (TRADOC) Maneuver Center of Excellence. The move involves the relocation of more than 300 tanks, support vehicles, and associated training activities to Fort Benning. Noblis interviewed Fort Benning master planners and trainers, and they expressed concern for the added operational tempo and associated stress on Fort Benning training ranges and environment. They indicated that a balance is needed between maneuver damage and use of training ranges and areas. An increase in the frequency and severity of storm events will likely add to adverse training area effects that will result from the increased frequency, training density, and load on the Good Hope heavy combat vehicle training range. Weather and ecological effects that could affect Armor School heavy vehicle training included the following:

- Flooding could restrict river crossing operations.
- Wet soil and subsoil causing increased maneuver damage and sediment run-off into impeded waterways could potentially limit heavy vehicle maneuver training.

- Lightning could endanger soldiers and equipment and temporarily halt field training.
- Overcast skies/cloud cover that can refract and amplify the levels and increase ranges of noise of vehicles and firing could potentially limit the use of specific training ranges and activities.
- Overcast skies/cloud cover that can refract and amplify the ranges of lasers and targeting devices could potentially limit the use of specific training ranges and activities.
- TES habitat management restrictions could limit heavy vehicle training in certain areas and during certain species mating times during the year.
- The Base Realignment and Closure (BRAC) and range construction processes require mitigation monitoring plans and goals that will need to consider climate-related effects.

Installation strategic planners and trainers indicated that some modification of training and range design and management will be required to adapt to local climate and environments. Moreover, adaptive scheduling and increased use of training simulators may be required over time to accommodate any potential increased schedule impacts of adverse climate-related weather effects.

Personnel also stated that modernization of military ground maneuver combat forces and weapon systems will significantly increase the range, speed, and lethality of future combat systems and units. The specific capabilities of these new weapons systems, munitions, and tactics, techniques and procedures (TTP) of future combat units is yet to be fully characterized. As such, their potential impacts on Fort Benning training ranges and environments and the impacts of long-term meteorological conditions and changes are also yet to be determined. The best management practices needed to mitigate adverse effects of these future combat systems and any potential climatic impacts still must be identified and evaluated. Examples of specific future concerns included:

- Unknown performance and range impacts of new weapons systems and munitions such as the M4 penetrator round causing uncertain berm requirements, safety ranges, etc.
- Increased use of flat, steel targets for immediate training feedback – impact causes fragmented munitions residue versus whole lead bullets to be exposed to weather and the environment.
- Increased ricochets with transition from M15A1 to M4 with penetrator – tungsten penetrator deforms not shatters.
- Lead bullets can shatter with little ballistic probability.
- Decreased size of lead fragments and increased environmental exposure.
- Lack of data for range safety parameters or environmental degradation and migration.
- Increased use of fire-and-forget wire-guided missiles versus current direct-fire tank rounds leaves wires on ranges.
- Potential firing of thermobaric warheads may be a concern.
- Increased use of small unmanned aerial vehicles (UAVs) primarily employing visual flight rules (VFR) encountering adverse weather may create air space control challenges and a need to restrict airspace – small UAVs may not be seen on radar and will need transponders in the future.

3.2.1.2 Natural Resource Management

Natural resource and conservation managers at Fort Benning must manage and maintain training areas and ranges in suitable condition for training activities while complying with environmental laws and requirements. The installation is subdivided into training compartments that are the principal natural resource planning units. Each unit is reviewed at least every ten years.

Current Natural Resource Management Activities

Fort Benning is being converted to a longleaf pine ecosystem which is the natural historical ecosystem for the region. The longleaf pine landscape is valued highly as a good open woodland type of training environment. Ecosystem management is used as the management protocol for the natural environment. The natural resource and conservation managers coordinate with trainers to understand what conditions are needed in the training areas and work to provide required conditions while still meeting environmental compliance requirements.

The upcoming transfer of the Armor School to Fort Benning by 2011 has created an ecological management challenge for natural resource managers to be able to manage training areas suitable for use by the large number of tracked and wheeled vehicles that will be part of the training regime when the Armor School begins operating at Fort Benning. Preparing for this move has been the focus of much of the recent planning.

The longleaf pine ecosystem is a fire-adapted system, and prescribed burning is an important management tool at Fort Benning. Burn plans are prepared every year. Smoke management is an important element of the burning program and must still comply with the Clean Air Act (CCA) requirements.

Climate Change and Natural Resource Management

Climate change is not currently a consideration in day-to-day management for natural resources. Managers also stated that climate change was not yet a subject in discussion with their professional colleagues in the state of Georgia government or with other regional federal environmental managers.

When presented with a possible climate change scenario during the Noblis interviews, Fort Benning managers felt that the ecosystem could change to a drier savannah type of community. They would have concern about how changes could affect the natural burning regime and the erosion control measures required under the different future conditions. They stated that they may need to use an adaptive management approach because they cannot prevent the changes from occurring.

Managers stated that they do not have local climate change information to use for planning and management. Examples of what were considered “local” information were given as the Georgia Fall Line Region or the Georgia Atlantic Coastal Plain area. Information needed at that scale included how the climate will change, how fast these changes are likely to occur, and how the ecosystems would respond to weather and climate drivers.

3.2.1.3 Environmental Compliance

Environmental compliance is an important focus of management activities at Fort Benning. Installation management and unit training personnel expressed concern that some extremes of adverse weather could possibly affect installation training environments and ecology. Over time these weather effects could affect Fort Benning compliance with regulatory requirements such as the Clean Air Act (CAA), Endangered Species Act (ESA), impeded waterways, and wetlands management.

Threatened and Endangered Species Management

Threatened and endangered species management is a significant challenge to maintaining access to training lands. The red cockaded woodpecker (RCW) is the main species of interest, although there are also other species present on the base. The US Fish and Wildlife Service (USFWS) has established the number of RCW clusters rquired at Fort Benning, and managers are working towards meeting that goal. Prescribed burning is an important management tool for this species. The installation is held accountable for any loss of TES habitat and could potentially be required to compensate by removing other lands from training. Degradation of the existing Fort Benning RCW longleaf pine foraging habit might not comply with the DoD and USFWS RCW management guidelines nor foster creation of added habitat needed to help recover the species at Fort Benning in accordance with an existing USFWS Biological Opinion. Failure to meet five-year RCW management goals could affect current training and operations as well as future training of armor heavy units being relocated with the move of the Armor School from Fort Knox, KY to Fort Benning.

Water Quality Compliance

An increase in the frequency and intensity of storms could significantly affect the amount of sediment washed into the waterways of the Chattahoochee River, and that would cause water quality compliance issues for Fort Benning. This potential change together with the Armor School operation presents a significant challenge to erosion control and water quality management. If sediment runoff is not adequately controlled, the installation compliance status could be affected adversely, which could result in restrictions on maneuver and river crossing training and other operations that might cause further deposition of sediment in the waterways. Costly best management practices such as sediment catch basins, storm drains, and rock-lined channels could be required to control sediment runoff and maintain water quality compliance.

Clean Air Act Compliance

The Fort Benning and Columbus, Georgia, region is currently in compliance for criteria pollutants. However, more frequent extreme high-heat days could result in more opportunities for violations of ozone standards. Higher temperatures and more high-heat days cause extreme dry conditions and drought that could significantly increase the potential for training and range operations causing unplanned fires that produce smoke. Fort Benning is currently exempt from state of Georgia standards for PM 2.5 for dust and smoke. However, increased air stagnation could affect installation air quality and potentially affect current or new Armor School training. Such conditions could also affect the ability to carry out the current prescribed burning program needed for environmental management of training areas and ranges. Dry conditions and drought during the previous five years has limited some training with pyrotechnics and grenade simulators and live firing with tracers because of the increased chance of unplanned wild fires.

Wetlands Management

Higher and more frequent extremes of temperatures could cause dry conditions and drought that would limit or eliminate the potential for on-post wetlands banking at Fort Benning. This situation would require Fort Benning to ask the USACE to identify and purchase off-post wetlands banking options and increase the cost of construction for new training and operational ranges that may affect on-post wetlands.

3.2.1.4 Built Environment

The built environment at Fort Benning consists of four cantonment areas and associated family housing, which accounts for approximately eight percent of the installation's 184,000 acres, and supports a daily population of approximately 120,000 people. Interviews with housing and civil engineering staff, as well as review of installation environmental impact statements, did not identify any existing problems that may be worsened by future climate change. Water supply was identified as a potential future problem, especially given several years of drought affecting flows in the Chattahoochee River that runs through Fort Benning. However, most of the installation's water comes from underground wells in well-developed aquifers. Additional development, either in terms of training areas or expansion of built areas, would continue to be supplied by additional wells, as needed. Surface water supplies augment underground sources.

Housing and engineering staff recognize that changing climate conditions with potential for increased temperatures will require some changes in designs regarding additional heat loads. An increase in severe storms may also increase the likelihood of flooding, but no specific built areas were identified that might be adversely affected.

3.2.2 Site Visit to Naval Base Norfolk, Virginia

A Noblis team visited Naval Base Norfolk, Virginia, during 17–20 November 2009. Noblis interviewed personnel responsible for operating forces missions and facility missions and activities. Personnel interviewed were responsible for military training, training areas and ranges management, infrastructure management, natural resources management and conservation, and environmental compliance.

Naval Base Norfolk is susceptible to weather effects and rising sea level. The installation elevation averages 8-10 feet above mean sea level, with the highest point being 16 feet above mean sea level. The water table is at seven feet below the surface, and excavation projects require de-watering. Storm water removal is a significant issue, and pumping stations are being considered for water removal. Observations concerning Naval Base Norfolk can be applied to other DoD bases and military installations in the Tidewater region and in the Mid-Atlantic climate region.

As the world's largest naval base, a key center for logistics and personnel movement, a hub for training, and a critical Command, Control, and Communications (C3) node, Naval Station Norfolk could be affected in many ways by climate change and must adapt effectively to maintain mission effectiveness. Staff and managers are sensitive to expected climate change effects. Some planning and farsighted actions are in progress in military construction, energy use, and land use, but there is a gap between the "science" and assumptions of predicted effects and the various "doctrines and standards" used to implement infrastructure changes. For example, temperatures are expected to rise, but current standards do not recognize higher ambient temperature for sizing air conditioning capacity. A number of land use and pier facility projects are planned or are underway, but estimates of expected sea level rise are not definitive.

Regionalization of Navy facilities was a prevailing theme in our review of Naval Base Norfolk. We interviewed a number of staff who were on "matrix- assignment" to Naval Base Norfolk, but also retained programmatic responsibility for the broader Navy Region Middle Atlantic headquarters. Functionally, they represented the base commander but also retained broader oversight for other bases and areas. Regionalization appears to be cost-effective, but appears to face challenges in instances when funds need to be applied to address emergent problems, e.g., cleanup from storm damage.

3.2.2.1 Operating Forces and Operational Support

Port Operations

The major aspect of operational support assessed during the Naval Base Norfolk visit was related to ship operational support, movement, and berthing. Naval Base Norfolk conducts about 1350 ship movements per year. Support includes ship arrivals and departures, magnetic silencing operations, alongside refitting, logistics support, and providing necessary utilities for in-port services and alongside training. Some of the current weather-related concerns include:

- Extreme tides and storm surge present major problems for water intrusion, disruption of utilities, and long-term exposure for piers.
- Wave motion resulting from movement of large ships in the channel causes ships to surge and equipment to be damaged.
- Harbor silting requires dredging, and this is expected to become more significant with increased precipitation that is predicted for this region.
- Expected pier life is 38 years, service in excess of 50 years is not unusual, and pier replacement projects are ongoing.
- Ship movements are highly dependent on weather, and operational tempo can be adversely affected by high winds and seas.
- Severe weather can affect access to pilots and safe channel transit and cause changes to operations.

Air Operations

Naval Base Norfolk Air Operations conducts over 100,000 flights each year, an average of 275 flights per day or one every six minutes. Over 150,000 passengers and 264,000 tons of mail and cargo depart annually on Air Mobility Command aircraft and other chartered flights from the airfield. Naval Base Norfolk is the hub for Navy logistics going to the European and Central Command theaters of operations and to the Caribbean.

Air operations are limited by adverse weather as they would be at any airfield. But additionally, the single-runway airfield is increasingly limited by prevailing winds that appear to be shifting with the passage of time, and crosswind limitations on landings and take-offs are becoming an increasing concern. Other recognized problems include the following:

- Operational equipment (landing lights, radar, and air traffic control) require air conditioning and will be increasingly affected by higher temperatures, precipitation, and environmental exposure.
- The area is vulnerable to rising sea level and storm surge effects from tropical cyclones and nor’easter storms in the Fall and Winter that can have significant effects on base operations and continuity of air operations.
- Only about 25 percent of aircraft can be placed in hangers.
- Helicopter equipment failures greatly increase in high-temperature environments.
- High temperature affects aircraft lift capacity, resulting in tradeoffs for fuel capacity, cargo or passenger capacity, and range.

Training

Several instances of adverse weather effects on training were cited during the visit:

- Shoreline erosion and loss of beaches due to sea level rise have affected coastal and amphibious operations (small unit operations) dependent on shoreline training facilities.
- Helicopter deck landing qualifications (DLQ) require helicopters to operate with deck-capable ships away from piers. For safety reasons, DLQs cannot be conducted at the pier. Consequently, retaining proficiency and certification requires availability of a number of ship-underway days during which DLQs can be completed. Availability of ships that are underway and the coincident aircraft availability for training dictate available training periods. Adverse weather effects can limit both platforms and the ability to complete certifications.
- Because of operational tempo and fuel-conservation concerns, ships are increasingly conducting "underway" training while moored to the pier (alongside training). Surface ships are currently limited to about 15 underway days per quarter for at-sea training. Some training cannot be conducted alongside, such as helicopter and sonar operations and gunnery training. Loss of underway training causes major impacts on ship readiness. Weather effects that affect underway training complicate this issue.
- Alongside training may be limited due to additional shore power and service requirements.
- The aggregate effects associated with climate change may be compounded and have effects on mission readiness. Concerns for higher operational tempo, reduced training time availability, weather effects, increased maintenance, and platform performance in harsh operational environments may reduce overall mission effectiveness and operational safety margins.

Ship Operations

Some secondary effects of climate change were noted during discussions with operating forces:

- The effects of condenser and seawater intake fouling due to higher water temperatures and changes in prevailing marine species needs to be evaluated.
- Injection temperatures are rising and may limit full-power operations.
- Shipboard air conditioning capacity is severely strained in high-temperature environments and degrades both shipboard living and working conditions, as well as operation of weapons systems.
- Corrosion control is increasingly difficult in high temperature and high humidity environments.
- Optimum Track Ship Routing (OTSR) for ship transits may be affected by changes in ocean currents due to climate change.
- Small boat training safety is adversely affected by heavy weather.
- Changes in ocean currents, salinity, and acidity will change sonar propagation. These effects have not been determined.

3.2.2.2 Natural Resource Management and Environmental Compliance

Naval Base Norfolk staff are responsible for Naval Base Norfolk, the Norfolk Naval Support Activity, and Craney Island. The base is largely an urban environment with few natural areas to be managed. As a result, natural resource management personnel are focused primarily on environmental compliance. Personnel are responsible for reviewing environmental permits and for complying with the requirements of the National Environmental Policy Act (NEPA). There are no threatened and endangered species on any of the three facilities. Climate change is not currently a consideration in day-to-day environmental management at the Base.

Air quality personnel are responsible for permits and compliance for all Navy facilities in the Hampton Roads region, which is currently in compliance with ambient air quality standards. There has not been an air quality ozone alert day since 1996. There are air-quality notice days for sensitive populations about twice per year. Personnel are focused only on compliance, and there has been no discussion of climate change. A possible climate change effect scenario discussed during the Noblis interview was additional high-heat days that could begin to cause ozone alert days.

Personnel at Navy Region Middle Atlantic headquarters are responsible for several installations and deal with wildlife habitat, wetlands, and threatened and endangered species. Climate change currently is not a management issue or included in Integrated Natural Resource Management Plans. However, the NEPA group is beginning to consider how to incorporate this issue into analyses, although there is no Navy guidance yet on this issue. Climate change effects that could be envisioned were effects on tidal wetlands and threatened and endangered species habitat and losing coastal beach and sand dune training areas to sea level rise. Personnel were not aware of any sources of climate change data. It was stated that climate change may be considered in the future if it is mandated.

3.2.2.3 Built Environment

"As-built" infrastructure is basically the same across all DoD installations, excepting for age, compliance with current energy standards, and susceptibility to climate change. The large built infrastructure at Naval Base Norfolk presents particular challenges due to age, vulnerability to sea level rise, and storm effects. Naval Base Norfolk's real property includes over 500 buildings and 13 million square feet of space with a plant replacement value (PRV) of over $4.2B.[1]

The base has a long-term approach to demolition of old infrastructure and consolidation into energy-efficient and compliant buildings. Consolidation and relocation of tenants is part of an ongoing planning process.

About 45,000-55,000 vehicles pass through the gates each day, including over 1000 commercial vehicles. Little public transportation is available. Plans for constructing light rail to the facility have been deferred to 2026.

Infrastructure support is reportedly underfunded at about 70% of requirements. This is a particular concern for Naval Base Norfolk due to its aging infrastructure. While many of the expected climate change effects can be addressed within existing processes, costs will be higher and decision points for remediation and adaptation may not be clear. Compounded effects of wetting and flooding, heating, ground water in-leakage, mold, and infrastructure degradation from the effects of sea level rise, higher temperatures, and weather damage will make infrastructure sustainment more costly. Facility sustainment models should consider climate change effects in order to more accurately predict long-term maintenance and repair costs.

Pier utility services are currently affected by rising sea level. As piers are replaced, long-range predictions of sea level will be required in order to optimize design.

[1] Base Structure Report – Fiscal Year 2009 Baseline, page DoD -73

Naval Base Norfolk has one 8300 foot, fixed-orientation airstrip that is subject to flooding during storms. No known options were identified for additional or alternative construction. Several days are required for area cleanup and restoration of services. As sea level rises, the effects of storm surge are expected to be exacerbated.

Approximately 75% of the airstrip is asphalt and adversely affected by temperature, sea air, and occasional inundation. The runway and servicing areas are subject to heating effects. Heavy aircraft "dent" the surface. Aircraft occasionally require ground equipment to pull them out of dents prior to taxiing. The dented areas subsequently require patching.

Only about 25% of aircraft are in hangers. Aircraft stored outside are exposed to salt air, seawater spray, and potential area inundation. No known land options for construction of additional hangers were identified during the interviews.

Wind direction appears to be gradually shifting and may result in the airfield losing utility because of cross-wind operations. This is major concern as the airfield has only one fixed orientation runway.

4 Implications for Policy and Practice

The findings in Section 3 have some general implications for DoD policy and practice regarding the development and use of climate change information and its use to assess effects on installations and missions. In order for DoD to train, equip and deploy its forces and to sustain installation resources into the future, it will need to provide the right climate change information to analysts and decision makers, work collaboratively with other agencies with similar needs and interests, and implement a framework and processes for climate change risk management. The goal must be to ensure that information leads to action and action leads to mission sustainability.

4.1 Providing the Right Climate Change Information

DoD policy makers, installation commanders and garrison staff have clearly stated that they do not presently have the “right” information to effectively manage the potential mission impacts posed by changing climatic conditions. Above all, they require information at a sub-state granularity that can support estimates of the expected type, magnitude, and timing of potential impacts that adversely affect training and operations. This information must have an acceptable level of uncertainty and be tied to various planning, acquisition, and construction cycles.

4.1.1 Provide the Relevant Climate Change Context for Installation Assessment

Providing useable data at appropriate installation and regional scales is essential to any effective effort to identify potential climate change effects and incorporate climate change into climate change planning and response. These activities will not be conducted in a vacuum given that climate change impacts will be felt by surrounding communities as well as DoD installations. Available information should be shared so that a common assessment of risk to the region can be achieved by federal, state, local government and private sector stakeholders and that mitigation measures be collaborative and mutually supportive.

At the federal level, DoD will not be acting alone, given that other federal agencies also have land and infrastructure management responsibilities. Federal managers have identified the need for local and regional climate change information, as illustrated in the following examples. GAO identified the need for site-specific information in a study conducted in 2009 (see Appendix E).[1] In a recent interview, the Director of the National Center for Atmospheric Research[2] stated that users need climate change information at the local level:

> Decisions about climate change will require much higher resolution models, because people are making decisions on a regional level. It’s a city, a particular business in a state, or a water resource manager who’s making up his mind. If you talk to people, they will tell you that one of the most important things they need is vey high-resolution regional climate models.

[1] U.S. Government Accountability Office. Climate Change Adaptation – Strategic Federal Planning Could Help Government Officials Make More Informed Decisions. GAO-10-113, October 2009.

[2] Nozik, K. 2010. Executive Interview: Eric Barron, Director of NCAR – Climate Modeling for Greater Good. Imaging Notes, Vol. 25, No. 1, Winter 2010.

The National Science Foundation, Department of Energy, and the Department of Agriculture are conducting a joint research program to produce high-resolution models for predicting climate change and the resulting effects at a localized scale.[3]

Several civilian agencies and the Navy have organized a partnership to predict climate change "on scales that matter." An interagency committee comprising representatives of the Navy, NOAA, Department of Energy, National Aeronautics and Space Administration, and National Science Foundation is working to develop models that can predict the effects of climate change on a short-term regional level. The initial focus of the effort is the Arctic region with other regions planned for the future. The activity is to develop earth system modeling linking the atmosphere, ocean, and ice. The modeling will be global in scale but at a high resolution.[4]

4.1.2 Focus on Information Needed to Sustain the Installation Mission

Personnel consistently stated to Noblis that "it's all about sustaining the mission" assigned to the installation. Climate change information must be relevant to assessing the specific issues of concern to operating and installation management personnel at specific facilities. Climate change information and products must be topically, geographically, and temporally relevant to their needs for their specific missions and activities that might be affected by climate change. Products and information must be technically correct, authoritative, and consistent with information accepted by higher echelons within the DoD organization. Information in several categories is needed at the installation level:

- Maintaining effective training, deployment, and force sustainment capabilities
- Sustaining the built environment
- Complying with regulatory requirements
- Keeping personnel safe

4.1.2.1 Maintaining Effective Training, Deployment, and Force Sustainment Capabilities

Installation managers and unit commanders constantly strive to meet training schedules that are necessary to achieve force readiness, meet deployment requirements, and sustain deployed forces. Climate change information is needed to determine how climate change can potentially alter the training environments, landscapes, and training conditions that would affect the ability to maintain required training rotation tempos and minimize impacts on conditions for deployment planning and preparation.

4.1.2.2 Sustaining the Built Environment

Installation infrastructure and the built environment are essential to support DoD training, deployment, and force readiness missions. This infrastructure includes buildings, utilities, transportation networks, communication systems, erosion control and storm water management systems, and training area instrumentation. Many of these systems are designed and built to specifications and standards derived from historic climate and weather information. Since the future climate may not be the same as the past, these standards and guidelines must be revised to anticipate changed conditions 50 or more years in the future. This is necessary so that facilities

[3] National Science Foundation. Improving Predictions of Climate Change and Its Impacts—New interagency program to generate high-resolution tools for addressing climate change. Press Release 10-044, 22 March 2010.

[4] Curry, K. Office of the Oceanographer of the Navy. Personal communication on 2 April 2010.

will be designed appropriately for conditions likely to exist within their useful lives. Alternatively, design and any construction in the near term must be undertaken with the expectation that modification may be necessary due to future climate change effects.

4.1.2.3 Complying with Regulatory Requirements

Climate change is likely to cause environmental and ecological changes that have the potential to complicate ongoing efforts by installation environmental managers to maintain compliance with the Endangered Species Act, the Clean Air Act, the Clean Water Act, and other environmental regulations. Failure to comply with these regulations can adversely affect the ability to conduct training and carry out other assigned tasks at an installation. Changing environmental conditions that affect habitat may work against current policies and plans to maintain compliance in the future. DoD in conjunction with other agencies will likely need to modify guidance and practice in response to these changes.

4.1.2.4 Keeping Personnel Safe

The safety of military and civilian personnel at installations is of paramount importance to commanders and managers. Unsafe conditions such as severe weather, lightning, high winds, extreme heat, or hypothermic situations can stop or alter training or disrupt daily installation activities. Commanders and planners will need to know how climate change can alter the occurrence, severity, and duration of situations affecting personnel safety in order to support the assessment of the effects of climate change on installation missions and operations.

4.1.3 Provide Information Needed to Develop Standards, Guidance, and Policy

Specifications, standards, directives, guidance, and policy were stated to be very important elements that specify and guide design, construction, planning, and management at the installation level. This guidance is usually based on historic data and information. An example is heating and cooling degree days for a region that are used for sizing heating and air conditioning systems during building design. Climate change will need to be accounted for in guidance and policy. This need is not unique to DoD. It can be expected that many other organizations in the private and public sectors will need to adapt current standards and practices to climate change.

4.1.4 Assure that Climate Change Information Supports Action

There will need to be an effective framework and process within DoD to use climate change information for analysis and assessment and to assure that the results are actionable at the installation level for adaptation and mitigation. DoD organizations will need to evolve and adapt to incorporate newly-developed climate change information and tools. Planning and execution processes within these organizations will need to develop the capability to analyze and assess emerging climate change information and data and incorporate products and results that are actionable at the installation level.

In keeping with the theme that information must lead to action (be actionable) and action must lead to sustainability, the requirement for information should be considered in the following terms:

- Must have the ability to identify expected climate changes within a specific geographic area and a temporal period.
- Can associate climate changes with effects on the built and natural environment.
- Can assess environmental effects in terms of mission effects and sustainability.

- Can identify mitigating measures to ensure that the resulting risk posed by climate change is kept at an acceptable level.

4.2 Working Across DoD and with other Agencies with Similar Needs and Interests

Much of the climate change information needed by DoD to undertake risk management activities is similar to that needed by other federal agencies. This is particularly the case for those agencies that are responsible for natural resources, such as the Department of the Interior (DOI), and for operation and maintenance of infrastructure, such as the U.S. Army Corps of Engineers Office of Civil Works and the DOI Bureau of Reclamation. Some of these agencies are already conducting climate change research. Cooperating and coordinating with these agencies and other appropriate non-government organizations would be very useful. The obvious benefit of doing so would be to prevent duplication of effort, take advantage of the collective expertise that is developing across the federal government, integrate research activities, and make the most effective use of federal resources applied to climate change issues.

Appendix A Modeling the Projected Effects of Climate Change

Most of the effects of climate change have their origins in changes to temperature, precipitation and sea level. Climate models can project future average annual temperature increases with high confidence due to the straightforward correlation between the radiative forcing by greenhouse gases (GHG) in the atmosphere and the resulting temperature rise. Projections for the average annual temperature increase in the continental U.S. are generally around 4°F for mid-century and 6° to 7°F late in the century, under a mid-range GHG emissions scenario. An average warming of that amount over the course of a year can have a profound effect on the occurrence and accumulation of snow, for example, but for the most part it is not a particularly illuminating indicator of what the future holds in a warmer world. More relevant are the projected increases in the extreme heat events: the occurrence of extremely hot days and the duration and intensity of heat waves. Although more difficult for scientists to project than average annual warming, this aspect of a warmer world will have profound impacts on the human condition.

Much more difficult to predict than temperature are changes to precipitation—annual amounts, variations by season, and intensity—because precipitation and snowpack depend strongly on the topography occurring at smaller geographic scales. The general circulation models (GCMs) that have produced most of the temperature and precipitation projections to date are not only run at coarse *horizontal* resolutions of about 150 miles (two to three hundred km), but they also do not contain detailed or accurate *vertical* information. GCMs yield average precipitation projections on sub-continental scales, but these are not useful for predicting future precipitation in a more localized area or in addressing the host of hydrological parameters relating to precipitation.

Visions of the future are termed projections rather than predictions because they are made under a set of assumptions that correlate to one of six specific scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) for global GHG emissions over the course of the 21st century, as shown in Figure A-1. Different research groups conduct modeling under different scenarios, the most common being the highly optimistic B1, the mid-range A1B, and the more pessimistic A2 or A1F1 scenarios.

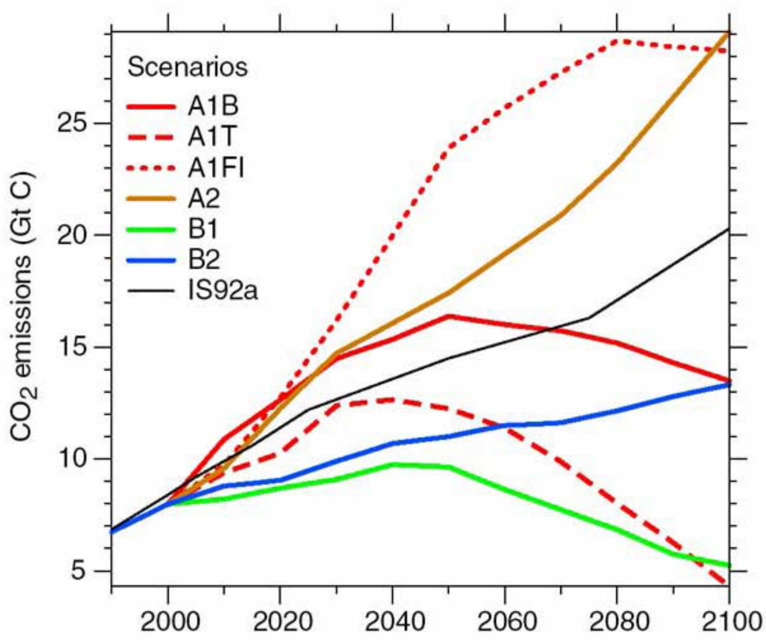

Figure A-1. The IPCC GHG Emissions Scenarios Used in Climate Change Modeling

In order to model with confidence the temperature and precipitation changes projected for a given geographic location — especially temperature extremes and precipitation changes — it is necessary to use a modeling approach called downscaling. Downscaling combines the modeling results from GCMs with information on a smaller regional scale to yield spatial resolutions of about 10 miles. Although downscaling produces far superior results compared to GCMs, the capacity to conduct this modeling is just emerging and not yet widespread. Therefore the regional-scale modeling results described in Appendix B are a combination of state-of-the-art downscaling methods and more coarse efforts to apply GCMs at somewhat finer resolution, depending on the availability of data for a given part of the country.

To assess the coming effects of sea level rise, we need to understand the four contributions to the relative sea level rise observed at a given location. These are changes to the following:

- The *amount* of water (melting land ice)
- The *volume* of a given mass of water (which depends on temperature and salinity)
- The *distribution* of that water (due to *sea surface height gradients* caused by thermohaline ocean circulation driven by differences in temperature and salinity)
- Vertical land movement (such as subsidence and tectonic uplift).

The first three are connected since melting ice alters salinity, and ocean circulation is driven by differences in temperature and salinity. The first two factors are felt more or less equally around the globe to yield an average global sea level rise. The second two contributions vary depending on location and determine the local sea level rise experienced relative to a point on land. There is still considerable uncertainty in estimates of average global sea level rise, but recent estimates for 2050 are about 40 cm (16” ± 4”) and for 2100 are in the vicinity of 1.25 m (4’ ± 1’). [1,2,3,4]

The regional projections described in Appendix B discuss predictions of sea level rise higher than the global average due to vertical land movement in the area and ocean circulation patterns occurring along the coast. Storm surge, watershed discharge, and tidal cycles also contribute to temporary high water levels occurring at the shore, and the combined effects of all of these contributions must be considered in assessing longer-term impacts on coastal military installations.

Although increased storm activity is frequently cited as one of the threats projected to result from climate change, the latest research into this correlation has not produced conclusive evidence that climate change is likely to result in increased tropical cyclone activity. Although a long-held assumption is that the wind speeds of tropical cyclones are a function of sea surface temperature, this is too simplistic. Projections of storm intensity, duration, and frequency (which together comprise the power dissipation index, PDI, as measured over the course of a year) are determined by various factors, such as the potential maximum wind speed (not to be confused

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[1] Vermeer, M. and Stefan Rahmstorf, 2009. Global sea level linked to global temperature. *Proc. Natl. Acad. Sci. U.S.A.*, **106**(51), 21527–21532, doi:10.1073/pnas. 0907765106.

[2] Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick, 2009, Climate change scenarios and sea level rise estimates for the California 2008 Climate Change Scenarios Assessment, Public Interest Energy Research Program Reports, Publication # CEC-500-2009-014-D, California Energy Commission, Sacramento, CA, 62 pp.

[3] Messner, S., S.C. Miranda, K, Green, C, Phillips, J. Dudley, D. Cayan, E. Young, 2009. Climate Change-Related Impacts in the San Diego Region by 2050. California Energy Commission, Public Interest Energy Research (PIER) Program. Publication #CEC-500-2009-027-F.

[4] Pfeffer, W.T., J. T. Harper, S. O’Neel, 2009. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science* **321**, 1340 (2008); DOI: 10.1126/science.1159099.

with the actual attained), the vertical shear of the horizontal wind, and vorticity. Wind shear, for example, is projected with high confidence to increase with global warming, and it is also widely recognized as an inhibitor of tropical cyclone activity. The tentative conclusion reached by some recent results is that global warming will reduce the global frequency of tropical cyclones, though it may increase their intensity in some locations.[5,6,7]

Further complicating the picture is that the various factors affecting storm intensity, duration, and frequency vary in different ocean basins. In the tropical North Atlantic — which gives rise to the hurricanes striking the U.S. Gulf and East coasts — PDI is strongly correlated with sea surface temperature. As a result, PDI has been increasing over the past several decades as sea surface temperature has been increasing. Even so, evidence does not exist to conclude that the Atlantic — including the mainland U.S. — will experience increased intensity or frequency of tropical cyclones in the future as a result of global warming. In fact, Emanuel et al. (2008) cite recent work projecting that storm activity will decrease in the tropical North Atlantic, probably due to the increased vertical wind shear predicted to occur over the North Atlantic in a warmer world.

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[5] Emanuel, K.A., 2007: Environmental factors affecting tropical cyclone power dissipation. *Journal of Climate*, 20(22), 5497- 5509.

[6] Emanuel, K., R. Sundararajan, and J. Williams, 2008: Hurricanes and global warming: results from downscaling IPCC AR4 simulations. *Bulletin of the American Meteorological Society*, 89(3), 347-367. *Hereafter referred to as Emanuel et al., 2008.*

[7] Bengtsson, L., K. I. Hodges, M. Esch, N. Keenlyside, L. Kornbleuh, J.-J. Luo, and T. Yamagata, 2007: How may tropical cyclones change in a warmer climate? *Tellus*, 59A, 539–561.

Appendix B Regional-Scale Projections of Climate Change

For purposes of this document, the conterminous United States (CONUS) is divided into eight regions based on the availability of regional climate change data. States included in each region are noted to clarify the geographic range, but the regions do not adhere strictly to state lines. As explained in Appendix A, the amount and quality of information on climate change effects for a particular region in the U.S. varies depending on the capability of different research groups to conduct downscaled modeling. Information is included on the status of climate change modeling for each region.

To facilitate comparison among the regions, all results are expressed in terms of the mid-range A1B Intergovernmental Panel on Climate Change (IPCC) scenario if possible, at times by approximating the A1B projection as midway between projections for B1 and either A2 or A1Fl scenarios. In terms of timeframes, most researchers report their projections as averages over the course of 30 years. Therefore, although some reports model in smaller increments, most references to "mid-century" are for the period from 2035 to 2065, while "late in the century" refers to the last 30 years of the century. Tables B-1 and B-2 present summaries of expected mid-century and late in the century climate change effects.

B.1 Arid Southwest (AZ, NM, southern NV)

TEMPERATURE: A downscaling analysis for the Colorado River Basin as a whole projects that temperature will increase by about 4° to 5°F by mid-century and 5° to 8°F by late century for the B1 and A2 scenarios, respectively.[1] Taking the mid-points as an approximation of A1B: 4.5°F (2.5°C) and 6.5°F (3.6°C) for mid- and late-century, respectively. scenario

EXTREME HEAT: Extreme heat events in the Southwest are projected to increase in frequency and duration, with extreme heat events defined as being in the top 5% of the daily temperature range. By the late 21st century, most of the Southwest is projected to experience about 60 to 70 days of additional heat wave days per year under the A2 scenario. The mean length of heat waves in the southwest is projected to increase by between 6 to 12 days, depending on the location, and this is more than other regions of the country.[2]

PRECIPITATION: While there is a consensus that precipitation will decrease, the magnitude is still uncertain,[3,4,5] and severe droughts are projected.[6]

1 Christensen, N. S. and D. P. Lettenmaier, 2007. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. Hydrol. Earth Syst. Sci., 11, 1417–1434. Hereafter referred to as Christensen and Lettenmaier, 2007.

2 Diffenbaugh, N.S., J.S. Pal, R.J. Trapp, and F. Giorgi, 2005: Fine-scale processes regulate the response of extreme events to global climate change. *Proc. Natl. Acad. Sci. U.S.A.*, 102(44), 15774–15778, doi:10.1073/pnas.0506042102.

3 Weiss, J.L., C.L. Castro, and J.T. Overpeck. Climate, Drought, and the Changing of the Seasons in the Southwestern U.S.A. *J. Climate*, submitted with revisions.

4 Christensen and Lettenmaier, 2007.

5 Seager, R., Ting, M., Held, I., Kushnir, Y., Lu, J., Vecchi, G., Huang, H.-P., Harnik, N., Leetmaa, A., Lau, N.-C., Li, C., Velez, J., and Naik, N., 2007. Model projections of an imminent transition to a more arid climate in southwestern North America, Science 316, 1181–1184, doi:10.1126/science.1139601.

6 ibid

Table B-1. Summary of Projected Regional Climate Change Impacts in the Continental U.S. by Mid-Century. Projections with fairly high confidence shaded light blue; low degrees of certainty are shaded grey

Sce-nario	Temp. (°F)	Extreme Heat Events	Precipitation Change	Snow	Stream Flow	Sea Level Rise (local issues with)
Northeast						
A1B	4.1°	Additional 10 to 30 days of extreme heat (90th historical percentile) per year (A1FI scenario)	12-13% increase in winter, with more intensity	Decline in snow volume about 45% (40% B1, 50% A1FI)	Higher in winter (flood risk); lower in summer (drought risk)	Subsidence along much of NE coast from Cape Cod to NJ, plus ~4" additional SLR due to ocean circulation.
Mid-Atlantic (NC to NJ)						
A1B	4°	Number of days >90°F projected to go from 30 to 50; number >100°F from 2 to 8	7% increase; more intense rain during storms	A decline in snow volume of about 35%	More runoff into Chesapeake	From NJ to Cape Hatteras there is subsidence due to post-glacial rebound and additional 2" of SLR due to ocean circulation
South						
A1B	3°	Extreme heat much more common: 21 days/ year >100 F >50% likely	Increased intensity	N/A	Likely reduced due to increased evapotranspiration	Subsidence in most areas; Coastal Louisiana, east Texas especially vulnerable; also SC though less so
California						
A1B	3.6°	21 extremely hot days per year: only 2 now; Very rare heat waves 17x more frequent	A decline of 5% to 15%	40% less snow in Sierra Nevada mountains; Years with >90% less snow than historical to become common		Vertical land movement not an issue
Pacific Northwest						
A1B	5°		Small (+1% to 2%)	40% decline in spring snowpack	Peaks shift closer to winter	Some areas threatened by subsidence, e.g., southern Puget South
Southwest						
A2	4.7° (4.5° A1B)	~30 to 35 additional extreme heat days (95th historical %) per year	Decrease, magnitude uncertain	Decline in mountains outside the region, affecting stream flow	Decline in flow of Colorado River of roughly 10%	N/A
Mountain West						
A2	4.6°		Uncertain	25% decline in spring snow in CO River Basin		N/A
Midwest & Plains						
A1B	3°	90°F heat waves almost twice as long; Consecutive 100°F days ~3 times as long; 42 days >90°F, up from 15	For MI, IN, IL, WI: annual increase but summer declines can be significant		Higher in winter and spring, increasing flood risk	N/A

Table B-2. Summary of Projected Regional Climate Change Impacts in the Continental U.S. by Late in the Century (2080s). Projections with fairly high confidence shaded light blue; low degrees of certainty are shaded grey.

Sce-nario	Temp. (°F)	Extreme Heat Events	Precipitation Change	Snow	Stream Flow	Sea Level Rise (local issues with)
Northeast						
A1B	6.7°	Additional 20 to 40 days of extreme heat (90th historical %)/year (A1FI)	25% increase in winter, with more intensity	Decline in snow volume about 70% (54% for B1, 85% A1FI)	Higher in winter (flood risk); lower in summer (drought risk)	Subsidence from Cape Code to NJ, compounded by ~8" additional SLR due to ocean circulation
Mid-Atlantic (NC to NJ)						
A1B	6°	Number of days >90°F projected to go from 30 to 75; # >100 F to go from 2 to 17	>5" rain during a storm 3 times more likely	A decline in snow volume of about 50%	More runoff into Chesapeake	Additional SLR of 10": 6" subsidence from NJ to Cape Hatteras + 4" of SLR due to ocean circulation.
South						
A1B	6°	Heat events truly rare now (once in 20 years) 10 x more frequent	Increased intensity	N/A	Likely reduced due to increased evapotranspiration	Subsidence in most areas; Coastal LA, east TX and SC especially vulnerable
California						
A1B	6.3°	34 extremely hot days per year: up from 2; Heat waves very rare now much more frequent	A decline of 5% to 15%	69% less snow in Sierra Nevadas; Years with mtn snow <10% historical to become normal		Vertical land movement not an issue
Pacific Northwest						
A1B	10°		Small (+1% to 2%)	65% decline in spring snowpack	Key watersheds for water supply more rain-dominated or entirely so	Some areas threatened by subsidence, e.g., south Puget South is subsiding and has tidal range >14'
Southwest						
A2	8° (6.5° under A1B)	60 - 70 additional extreme heat days (95th %) per year; Heat waves 6 - 12 days longer	Decrease, magnitude uncertain	Decline in mountains outside the region, affecting stream flow	Decline in flow of Colorado River of roughly 14%	N/A
Mountain West						
A2	8°		Uncertain	29% less spring snow in CO River Basin	Decline in flow of Colorado River of roughly 14%	N/A
Midwest & Plains						
A1B	5.5°	90°F heat waves to last 2 to 3 times longer; 100°F waves: 5 or 6 times as long; 54 days >90°F, up from 15; Higher humidity	For MI, IN, IL, WI: annual increase but declines can be significant		Higher in winter and spring, increasing flood risk	N/A

ANNUAL FLOW OF THE COLORADO RIVER: There is agreement that there will be less snow in the mountains that provide water to the area, and that snow will melt earlier in the year. More research is needed but there is a consensus among those who have been modeling flow in the Colorado River that it will decline by roughly 10%.[7,8,9]

RESEARCH STATUS: Downscaling results for temperature and precipitation are still not available for the arid Southwest specifically, though some results are available for the greater region. However there is still overall consensus that the desert Southwest will be hotter and have less precipitation. A number of groups are modeling the hydrology of the Colorado River Basin, but there is disagreement regarding the magnitude of the changes.

B.2 California

SEA LEVEL RISE: The key study on sea level rise in California[10] did not identify local issues such as subsidence of particular concern for California. Their projections for global sea level rise are 30 to 45 cm (1' – 1.5') by 2050 (under B1, A2 and A1Fl; 1.25' under A2) and 90 to 140 cm (between 3' and more than 4.5') by 2100.

TEMPERATURE: 1°C to 3°C (1.8°F to 5.4°F) in mid-century, rising by a total of about 2°C to 5°C (3.6°F to 9°F) late in the century, for B1 and A2 respectively. Midway between these, approximating A1B: 2°C (3.6°F) mid- and 3.5°C (6.3°F) late-century. Summer is projected to warm by about 2°F more than winter: increases by late century are projected to be 7.5°F in the summer (from 1.5°C–6°C or 2.7°F–10.8°F) compared to 5.4°F in the winter (from 1°C–4°C or 1.8°F–7.2°F). The moderating effect of the ocean is expected to mitigate the temperature increases along the coast, to about 30 miles (50 km) inland.[11]

EXTREME HEAT: Very hot days (those exceeding the historical 95th percentile) are projected to increase from 8 per year now to about 21 in mid-century and 34 late in the century. Extended heat waves—those consisting of five or more consecutive days exceeding the 95th percentile—almost never occurred historically, but are projected to become much more common this century. Per 30-year period, occurrences of heat waves will go from 2 historically to 34 by mid-century and to 47 late in the century. (This information is for the Sacramento area only, from downscaled data, and is approximately under the A1B scenario (calculated as halfway between data for the B1 and A2 scenarios.)[12] A trend in the 1990s is toward more frequent humid heat waves, characterized not only by temperatures in the hottest 1% of historical temperatures, during both the day and night, but by high humidity at night. Such heat waves are predicted to occur more frequently in the future because they are "related to the availability of an anomalous and increasing moisture source west of Baja California," which is coincident with the trend of warming sea surface temperatures caused

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7 Christensen and Lettenmaier, 2007.

8 Hoerling M., D. Lettenmaier, D. Cayan and B. Udall. 2007. Reconciling Projections of Colorado River Streamflow. Southwest Hydrology, May/June 2007.

9 Hoerling, M. and J. Eischeid. 2007. Past Peak Water in the Southwest. Southwest Hydrology, Jan/Feb 2007.

10 Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick, 2009. Climate change scenarios and sea level rise estimates for the California 2008 Climate Change Scenarios Assessment. California Energy Commission, Public Interest Energy Research (PIER) Program. Publication #CEC-500-2009-014-D. *Hereafter referred to as Cayan et al., 2009.*

11 ibid

12 ibid

by global warming. The worst of these events so far, in 2006, caused widespread damage including the deaths of 1% of the state's dairy cows, a reduction in milk production of 10%, and great strain on water and electricity infrastructure.[13]

SNOWPACK: The average decline in snowpack in the Sierra Nevada Mountains over all elevations is about 40% by mid-century and 69% late in the century (averaging B1 and A2). Years with mountain snow accumulation less than 10% of the historical average (that is, a decrease of over 90%) are projected to be common by mid-century and the norm late in the century under the A2 scenario. In California, as in much of the West, snow in the mountains —especially in the spring — is a key source of fresh water.[14]

PRECIPITATION: Although uncertainty is high, "there is a disquieting preponderance of simulations that become significantly drier during the twenty-first century," with projections for 30-year averages mid-way and late in the century falling between 5% and 15% lower than the 1961–1990 average. The authors explain that such declines "are rivaling or exceeding the largest observed multi-decadal deficits within the modern California historical experience."[15]

WILDFIRES: Substantial increases are projected in the occurrence of large wildfires, by about 20% early in the century (2005 to 2035), 30% in the mid-century period (2035 to 2065), and 60% late in the century (2065 to 2100), under a mid-range scenario (halfway between B1 and A2).[16] California is prone to flash flooding and landslides due to its distinct wet and dry seasons, and fires exacerbate the impacts in both by burning stabilizing vegetation.

RESEARCH STATUS: A comprehensive body of research on the impacts of climate change in California was released in the spring of 2009 by a large number of research groups examining a broad range of sectors. Work on the first order climate variables--the regional modeling of temperature, precipitation and snow — was conducted by the research group of Dan Cayan of the Scripps Institution of Oceanography and colleagues. Some of the temperature and precipitation projections were modeled using statistically downscaling, the results of which were used to conduct hydrologic modeling of snow water equivalent using a Variable Infiltration Capacity model.

B.3 Mid-Atlantic (NC, VA, DC, MD, DE, NJ, PA, WV)

SEA LEVEL RISE: Sea level rise along the mid-Atlantic coast, from about New Jersey to Cape Hatteras, is being exacerbated by post-glacial subsidence, which can occur in areas that were not previously glaciated after nearby glaciers retreat. The effect amounts to roughly 6" per century if it continues at its current rate[17], though the rate of future post-glacial subsidence is not certain. Another factor, projected to occur over this century, is that sea level rise will be higher than the global average off the Mid-Atlantic coast, reaching roughly 4" (0.1 m) by the end of the century

13 Gershuniv, A., D.R. Cayan and S.F. Iacobellis. 2009. The Great 2006 heat wave over California and Nevada: Signal of an Increasing Trend. *Journal of Climate,* in press, DOI 10.1175/2009JCLI2465.1.

14 Cayan et al., 2009

15 Cayan et al., 2009

16 Westerling, A.L., B. P. Bryant, H.K. Preisler, T.P. Holmes, H.G. Hidalgo, T. Das, and S.R. Shrestha, 2009. Climate Change, Growth and California Wildfire. California Energy Commission, Public Interest Energy Research (PIER) Program. Publication #CEC-500-2000-046-F.

17 Neumann, J.E. et al. 2000. Sea Level Rise & Global Climate Change : A Review of Impacts to U.S. Coasts. Pew Center on Global Climate Change.

under the A1B scenario. The cause is a weakening of the Atlantic meridional overturning circulation (AMOC), which is projected with high confidence to occur along the northeast coast of North America during the 21st century. This analysis does not include melting of Greenland ice, the freshwater from which would further weaken AMOC and increase sea level rise in this location.[18]

TEMPERATURE: Approximating A1B as halfway between B1 and A2 results, an average warming of 3.5°F (1.9°C) is projected by mid-century and 6.2°F (3.4°C) late in the century. A seasonal difference is projected to emerge by late in the century, with summers warmer by an average of about 1.5 degrees.[19]

EXTREME HEAT: Under a mid-range scenario (half-way between B1 and A2), the number of days exceeding 90°F is projected to increase from 30 currently to more than 50 by mid-century and over 75 late in the century. The number of days over 100°F is projected to increase from its historical level of two days per year to eight days by mid-century and 17 days by late in the century.[20] The 2009 U.S. Global Change Research Program report[21] provided the maps shown in Figure B-1 that were produced from the statistically downscaled WCRP CMIP3 multi-model dataset under the A2 scenario. The figure shows the marked increase in the average number of days per year over 90°F projected for late in the century, as compared to the period from 1961 to 1979.)

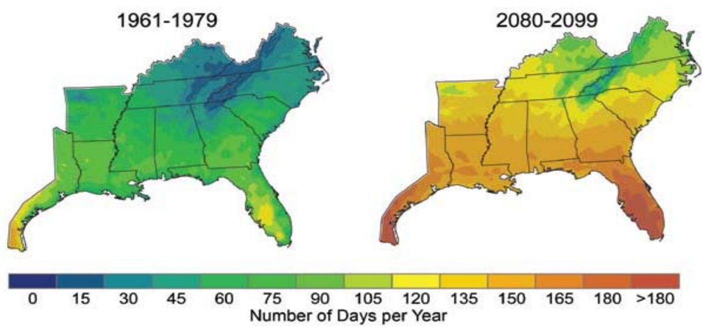

Figure B-1. The number of days of various temperatures in the South and mid-Atlantic for late in the century compared to historical.

PRECIPITATION: The amount and intensity of precipitation is projected to increase. Under the mid-range scenario (taken as half-way between B1 and A2), the projections are for a 7% increase by mid-century, with increased rain intensity during storms. Late in the century the increase is projected to be 11.5% (10.4% for B1 and 12.6% for A2), with the chance of more than 5" of rain during a storm three times more likely than today.[22] Diffenbaugh et al. (2005)[23] agree, finding that the mid-Atlantic region is predicted to have the most pronounced increase in CONUS in extreme precipitation events.

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[18] Yin, J., M.E. Schlesinger & R.J. Stouffer. 2009. Model projections of rapid sea-level rise on the northeast coast of the United States. *Nature Geoscience*, published online: 15 March 2009, DOI: 10.1038/NGEO462.

[19] Boesch, D.F. (editor). 2008. *Global Warming and the Free State: Comprehensive Assessment of Climate Change Impacts in Maryland.* Report of the Scientific and Technical Working Group of the Maryland Commission on Climate Change. University of Maryland Center for Environmental Science, Cambridge, Maryland. *Hereafter referred to as Boesch et al., 2008.*

[20] ibid

[21] Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009.

[22] Boesch et al., 2008

[23] Diffenbaugh, N.S., J.S. Pal, R.J. Trapp, and F. Giorgi, 2005: Fine-scale processes regulate the response of extreme events to global climate change. *Proc. Natl. Acad. Sci. U.S.A.*, **102**(44), 15774–15778, doi:10.1073/pnas.0506042102. *Hereafter referred to as Diffenbaugh et al., 2005.*

SNOW: The volume of winter snow is projected to decline dramatically, by about 35% in mid-century and 50% late in the century.[24]

RESEARCH STATUS: No downscaling research has been published for the mid-Atlantic, although at this point it is common for literature on the mid-Atlantic to apply results for the Northeast to the mid-Atlantic (see next section). In fact, the downscaling study of Hayhoe et al.[25] include New Jersey and Pennsylvania as part of the Northeast for those parameters relating to temperature and precipitation. For temperature and precipitation, Boesch et al. (2008) only used GCM data, though they chose those models that best reproduced observed 20th century climate. Boesch et al. (2008) also referred to unpublished work of Hayhoe, which is presumably based on downscaling.

B.4 Northeast (NY, CT, RI, MA, VT, NH, ME)

SEA LEVEL RISE: By the end of the century under A1B, sea level rise is projected to be about 8" (0.2 m) higher than the global average off the Northeast coast (south to about New York) due to the effects of ocean circulation. The cause is a weakening of the Atlantic meridional overturning circulation (AMOC), which is projected with high confidence to occur along the northeast coast of North America during the 21st century. This analysis does not include melting of Greenland ice, the freshwater from which would further weaken AMOC and increase sea level rise (SLR) in this location.[26]

TEMPERATURE: Annual regional surface temperature is projected to increase by 4.5°F (2.5°C) in mid-century and 8°F (4.5°C) late in the century under A2.[27] Averaging results for B1 and A2 gives an approximation of A1B of 2.3°C (4.1°F) and 3.7°C (6.7°F) for mid- and late-century, respectively. The increases will be significantly larger in the summer as compared to winter, and they are projected to be greater at higher latitudes and inland.

EXTREME HEAT: Late in the century under an A1Fl scenario, each year is projected to have twice as many days of extreme heat—an additional 20 to 40 days—where extreme heat is defined here to mean those that exceed the 1990 90th percentile threshold. The south-central portion of the region is projected to see the most increases in extreme heat.[28] This publication did not mention projections for mid-century, but if temperature changes are treated linearly over the century, the additional extreme heat would be 10 to 20 days by mid-century under A1Fl.

PRECIPITATION AND STREAM FLOW: Only small declines in summer rainfall are projected, but winter precipitation is projected to increase by about 10-15% by mid-century and 20-30% late in the century, under the B1 and A1Fl scenarios. Heavy precipitation is projected to occur more

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24 Boesch et al., 2008.

25 Hayhoe, K., C.P. Wake, T.G. Huntington, L. Luo, M.D. Schwartz, J. Sheffield, E. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T.J. Troy, and D. Wolfe. 2007. Past and future changes in climate and hydrologic indicators in the US Northeast. *Climate Dynamics* 28:381-407. *Hereafter referred to as Hayhoe et al., 2007.*

26 Yin, J., M.E. Schlesinger & R.J. Stouffer. 2009. Model projections of rapid sea-level rise on the northeast coast of the United States. *Nature Geoscience*, published online: 15 March 2009, DOI: 10.1038/NGEO462.

27 Hayhoe et al., 2007.

28 ibid

frequently and with greater intensity. Days with precipitation will be wetter by a projected 8-9% by mid-century and 10-15% late in the century, regardless of the emissions scenario.[29]

SNOW: The total volume of snowfall each winter season (snow water equivalence) is projected to decline about 45% by mid-century (40% under B1, 50% under A1Fl) and 70% late in the century (54% and 85% for B1 and A1Fl).[30]

STREAM FLOW: Greater variability is projected, with more high flow events in the winter, carrying with it a greater risk of flooding, and more frequent low flow events in the summer, increasing the risk of drought.[31]

RESEARCH STATUS: Sophisticated and thorough analyses were conducted by the research group of Katharine Hayhoe of Texas Tech University and colleagues. The 2008 paper applied both statistical and dynamical downscaling methods (finding the latter superior for precipitation in this region), while the 2007 work used only statistical downscaling. Hydrologic modeling used the Variable Infiltration Capacity (VIC) model.

B.5 South (TX, LA, MS, AL, FL, GA, SC, OK, AR, TN, KY)

SEA LEVEL RISE: Certain areas are experiencing rapid subsidence, mostly due to groundwater withdrawals but also due to the compaction of sediments deposited by rivers. Subsidence rates are highest in Louisiana and East Texas and then slow along the southern portion of coastal Texas and in the central Gulf (Mississippi-Alabama Sound).[32,33] If the current rates of subsidence continue, the Galveston area will subside, apart from the effects of global sea level rise, by 23.5 cm (9.25”) in 2050 and 47 cm (18.5“) by 2100. Subsidence at Grand Isle, LA is projected to be nearly double that, with 40 cm (16”) subsidence by 2050 and 80.5 cm (2’ 8”) by 2100.[34]

AVERAGE ANNUAL TEMPERATURE: Temperature increases are projected to be higher in the summer, although warming by mid-century is projected to be fairly mild: about 1.5°C ± 1°C (2.7°F) in winter and 2.0°C (3.6°F) in summer, under the mid-range A1B scenario. (Averaging these gives an annual increase of 1.8°C (3.2°F).) The study gave no value for late in the century, but if linear behavior is assumed over the century for temperature, the increase by late in the century would be roughly 6°F under A1B.[35]

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29 Hayhoe, K., C.P. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A. Hertel, and D. Wuebbles. 2008. Regional climate change projections for the Northeast U.S. *Mitigation and Adaptation Strategies for Global Change* 2008, vol. 13, issue 5, pages 425-436.

30 Hayhoe et al., 2007

31 ibid

32 Neumann, J.E. et al. 2000. *Sea Level Rise & Global Climate Change : A Review of Impacts to U.S. Coasts.* Pew Center on Global Climate Change (see Figure 2).

33 Keim, B.D., T.W. Doyle and V.R. Burkett, 2008. Chapter 3 : How Is the Gulf Coast Changing? In: *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.* Synthesis and Assessment Product 4.7 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [Savonis, M.J., V.R. Burkett, and J.R. Potter (eds.)], Washington, DC, USA. *Hereafter referred to as Keim et al., 2003.*

34 ibid

35 ibid

Extreme Heat: Although in-depth projections with high resolution have not yet been published for the South, the 2009 U.S. Global Change Research Program report[36] presented the maps shown in Figure B-1 *{in the section on the mid-Atlantic}*, made from the statistically downscaled WCRP CMIP3 multi-model dataset. Figure B-1 shows the marked increase in the average number of days per year over 90°F projected for late in the century under the A2 scenario, as compared to the period from 1961 to 1979. Keim et al. project that by the middle of the century hot days currently viewed as rare are likely to occur at least every other year, with a better than 50/50 chance that 21 days per year will be hotter than 100°F (holds for all scenarios). By the end of the century, this study projects under a mid-range scenario that severe heat waves — that are currently so rare they occur only once every 20 years or so — will occur ten times more often in the southern and western portion of the South, and about eight times more often in the rest of the region.[37]

Precipitation and Stream Flow: It is uncertain whether the total amount of precipitation will increase or decrease but there are indications that intensity could increase. The amount of water in streams (stream flow) has not yet been projected with confidence, pending higher resolution results on precipitation, but there is a high level of confidence in future temperature increases. Given the projected increases in extreme heat in the Gulf and southeastern United States, a significant increase in evapotranspiration will result.[38] Unless the future under climate change brings additional precipitation to offset the resulting loss in stream flow, the enhanced evapotranspiration will reduce surface sources of water.

Storm Surges in Gulf: Even without considering sea level rise, NOAA's SLOSH model predicts potential surges of 7 m (23') in Category 3 storms, and up to 9 m (30') with Category 5, depending on the trajectory.[39]

Hurricanes: Evidence does not yet exist to conclude that the Gulf or Southeast coasts will experience increased intensity or frequency of hurricanes as a result of global warming**.** [40,41,42] This is in spite of the fact that the power dissipation index (PDI) of cyclones in the tropical North Atlantic is strongly correlated with sea surface temperature, and PDI has been increasing over the past several decades as sea surface temperature has increased due to global warming. (PDI, when taken over the course of a year, is a function of storm intensity, duration, and frequency.) The uncertainty in what the future holds appears to be due to confounding factors such as wind shear, which is projected with high confidence to increase with global warming. Shear is widely recognized as inhibiting tropical cyclone activity.

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36 Global Climate Change Impacts in the United States, Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press, 2009.

37 Keim et al., 2003

38 ibid

39 ibid

40 Emanuel, K.A., 2007: Environmental factors affecting tropical cyclone power dissipation. *Journal of Climate*, 20(22), 5497- 5509.

41 Emanuel et al., 2008.

42 Bengtsson, L., K. I. Hodges, M. Esch, N. Keenlyside, L. Kornbleuh, J.-J. Luo, and T. Yamagata, 2007: How may tropical cyclones change in a warmer climate? *Tellus*, 59A, 539–561.

RESEARCH STATUS: The projections for temperature and precipitation made by Keim et al (2008) were not obtained through downscaling but are based on general circulation models that cover the whole region.

B.6 Coastal Pacific Northwest (WA, OR)

SEA LEVEL RISE – Parts of the region are subsiding while others are being uplifted. The southern portion of Puget Sound, for example, is believed to be subsiding most rapidly, although there seems to be some debate about this. The usual subsidence rate cited for southern Puget Sound is 2 mm/year, which if extrapolated linearly for 100 years would result in a total subsidence of 20 cm that would need to be added to global sea level rise.[43] Regardless of the exact extent of subsidence over the coming century, the southern portion of Puget Sound faces an additional challenge from the large diurnal tidal fluctuation there of 4.4 m (14.5 ft).[44]

PRECIPITATION – There is considerable variability in projections among models but the average among them gives a small increase of only 1% or 2%. Increases in extreme high precipitation are projected over the next half-century, particularly around Puget Sound.[45]

TEMPERATURE – Under the A1B scenario, increases are projected to be 2.9°C (5.2°F) by mid-century and 5.4°C (9.7°F) late in the century.[46] Under A2, days of extreme heat are projected to double by late in the century along the coast of the Pacific Northwest and increase by roughly 30 days in the rest of the region (with extreme heat defined as the top 5% of temperature relative to historical).[47]

SNOWPACK – April 1 snowpack in the mountains is projected to decline by nearly 30% in about 20 years, 40% by mid century, and 65% late in the century. The amount of mountain snowpack that exists as of April 1 is important because it represents the amount of water that will be released into streams and reservoirs later in the spring and summer. [48]

STREAM FLOW – The volume of water in streams as a function of the time of year will shift dramatically over this century, as winter and spring precipitation increasingly becomes rain rather than snow, and the snow melt occurs earlier in the year. This has important implications for water supply and storage since the timing of stream flow determines when water is available. Watersheds currently dominated by snowfall, such as the Columbia River, will become "transient" (significant rainfall as well as snow), which will increase stream flow in the winter and reduce it in the spring and summer. Streamflow in transient watersheds like the Yakima River will shift away from

[43] Mote, P., A. Petersen, S. Reeder, H. Shipman, & L.W. Binder. 2008. *"Sea Level Rise in the Coastal Waters of Washington State"*. University of Washington Climate Impacts Group and the Washington Department of Ecology.

[44] Finlayson, D. 2006. The geomorphology of Puget Sound beaches. Puget Sound Nearshore Partnership Report No. 2006-02. Published by Washington Sea Grant Program, University of Washington, Seattle, Washington.

[45] Climate Impacts Group, 2009. *The Washington Climate Change Impacts Assessment,* M. McGuire Elsner, J. Littell, and L Whitely Binder (eds). Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, Washington. *Hereafter referred to as Climate Impacts Group, 2009.*

[46] ibid

[47] Diffenbaugh et al., 2005, Figure 1a.

[48] Climate Impacts Group, 2009

summer into spring and finally into winter as the system becomes dominated by rainfall late in the century rather than snowfall.[49]

Research Status: The University of Washington Climate Impacts Group has a long history of conducting state of the art modeling of climate change. The 2009 publication by the Climate Impacts Group is the latest synthesis of their results, which are also updated regularly on their web site at http://cses.washington.edu/cig/fpt/ccscenarios.shtml. The group used statistical downscaling to model temperature and precipitation and two hydrologic models for snow pack and stream flow: the Variable Infiltration Capacity (VIC) model, which has a 12 mi^2 grid appropriate for looking across larger areas of the region, and the Distributed Hydrology Soil and Vegetation Model (DHSVM), with a much finer scale of about 150 m suitable for looking at sub-regions such as Puget Sound. Although the title of the paper refers only to Washington, the scope of the research was based on the watersheds found in the Columbia River Basin and so it included Washington, Oregon, Idaho, western Montana, part of British Columbia, and very small parts of adjacent states.

B.7 Mountain West (ID, MT, WY, CO, UT, Northern NV)

TEMPERATURE: The increases in average temperature are projected to be 4.6°F by mid-century and 8°F by late in the century under A2.[50] Approximating the mid-range A1B scenarios from the mid-points gives 2.3°C (4.1°F) and 3.5°C (6.37°F) for mid- and late-century. Late century seasonal data is not available but in mid-century summers are projected to warm 2°F more than winters.[51]

PRECIPITATION: There is insufficient data to provide clear trends for precipitation, though there are some indications of more extreme precipitation in the mountains in some areas.[52,53]

SNOW: Under A2, April 1 snowpack in the Colorado River Basin is projected to decline by 25% in mid-century and 29% by late in the century.[54]

STREAM FLOW: The groups conducting research on projected changes to the flow of the Colorado River have not reached consensus on the magnitude of the decline, but there is consensus that it will drop, with an estimate of roughly 10% by mid-century (11% ± 7%).[55] The latest estimate for late in the century is a decline of about 14%, according to Ray et al. (2008), citing a personal communication from Dennis Lettenmaier, one of the preeminent researchers on this topic. The flow of the Colorado River is critical to the West as it supplies water for much of the population in the southwest and California.

RESEARCH STATUS: Downscaling results specific to the region have not been published for temperature and precipitation. Much research has been conducted relating to the flow of the

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49 ibid

50 Christensen & Lettenmaier, 2007

51 Ray, A.J. et al. 2008. Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation, CU-NOAA Western Water Assessment.

52 ibid

53 Diffenbaugh et al., 2005

54 Christensen & Lettenmaier, 2007

55 Hoerling M., D. Lettenmaier, D. Cayan and B. Udall. 2007. Reconciling Projections of Colorado River Streamflow. Southwest Hydrology, May/June 2007.

Colorado River, as discussed above. Dennis Lettenmaier's group is in the process of developing improved projections.

B.8 Central North (The Mid-West and Plains: ND, SD, NE, KS, MN, IA, MO, WI, IL, IN, MI, IN, OH)

TEMPERATURE: Downscaling has been conducted for temperature for the region encompassing Michigan, Indiana, Illinois and Wisconsin, which will generally hold true for the region as a whole. Increases are projected to be 3°F by mid-century and 5.5°F late in the century, taking an average of the B1 and A1Fl scenarios, which approximates the A1B scenario.[56]

EXTREME HEAT: Heat waves and higher humidity are projected to plague the region. Heat waves with the severity of the 1995 heat wave, which historically occur about once every 30 years, are projected to occur roughly once a year by mid-century and twice a year late in the century. The number of days over 90°F are projected to increase from only 15 currently to 42 days by mid-century and 54 by late century. Days exceeding 100°F occur only twice a year now, and are projected to be six times as common by mid-century and ten times by late century (i.e., 12 days and 20 days for mid- and late-century). All of these figures are the average of B1 and A1Fl. By mid-century 90°F heat waves are projected to almost double in duration, while stretches of consecutive 100°F days will be about three times as long. The number of days topping 90°F is projected to rise from 15 to 42. By late in the century, 90°F heat waves are projected to last two to three times longer, and 100°F waves five to six times as long. The numbers of days over 90°F are projected to reach 54.[57]

PRECIPITATION: Downscaling results are available for precipitation for the four state block of Michigan, Indiana, Illinois, and Wisconsin (plus the eastern part of Iowa). Overall annual precipitation there is projected to increase under all scenarios by late in the century, ranging from a few percent in eastern Iowa and southwestern Wisconsin to between 6% and 15% in southern Indiana. There are important seasonal differences projected: results for late in the century, under both A1B and A2, found that more precipitation is projected for all seasons except summer, when significant decreases are projected. Under both scenarios the summer declines become more pronounced moving from north to south, with drought projected to become even more of a problem in the southern portion of the region than it is now. The reduced summer rain is much more pronounced under A2 than A1B: under A2 the projections range from about 10% to 30% from north to south, while under A1B the reduced rainfall is only several percent in the north, in the teens in much of the central portion, and about 20% in southern and western Illinois. In fall and winter increasing precipitation is projected to be in the range of 6 to 15%, under both A1B and A2. Spring, however, is projected to see significantly more precipitation: about 30% in most areas under both scenarios.[58] Given the large spatial variability in precipitation, these results cannot be extrapolated to the region as a whole.

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[56] Hayhoe, K. & D. Wuebbles. 2007. Climate Change and Chicago: Projections and Potential Impacts. Chapter 2 of the Chicago Climate Action Plan.

[57] ibid

[58] Cherkauer, K.A. and T. Sinha. Hydrologic impacts of projected future climate change in the Lake Michigan region, submitted to Journal of Great Lakes Research.

STREAMFLOW: For the four state block of Michigan, Indiana, Illinois and Wisconsin, higher streamflows are projected for the winter and spring, increasing the risk of flood. Results for summer and fall depend on the scenario: under A1B modest increases in flow are projected for the summer, while changes can be in both directions in autumn, depending on the area. Under A2 the results are more unequivocal, with decreasing summer and fall streamflow up to about 15% projected for much of the region, although the south shows areas with increased flow as well. Overall, water flow in regional rivers is projected to increase, including annual average low flows.[59]

RESEARCH STATUS: Downscaling research is also available so far only for the limited four-state portion of the region.

59 ibid

Appendix C Installation Selection Criteria

Category and Criteria	Considerations
Regional climate data	
Availability for region with installations	Downscaling or other analyses are available
Robustness and completeness	Has estimates for a number of elements and other analyses
Types and range of forecast changes	Number of climate elements forecast and range given for forecast element changes
Uncertainty in changes	Want less uncertainty
Resolution	Downscaling grid needs to be able to be used for installation region
Climate-change related activities	
Mitgation and adaptation activities and studies	GHG emissions inventory, GHG reduction strategy and projects, adaptation strategy or plans
Climate-change related studies	requirements
Installation infrastructure and missions	
Infrastructure and facility operations	
Geographical location	On the coast, inland
Type, diversity, and size of "city" functions	Housing, transportation, public safety, recreation, utilities, public health
Type, diversity, and extent of mission support functions	Equip, train, support, and deploy warfighters
Susceptability to climate-change-related effects	Climate change forecasts are likely to result in measurable effects on facilities and operations
On-going studies availability	Existing studies by the installation, command, or civilian organization
Data availability	Master plans, sustainability plan, operational data
Current reliance on off-installation services	Utilities, energy
Current base operations and regional issues	Water supply, air quality, water quality
Installation training and range lands	
Size and diversity of land manuever areas and ranges	Types of ecosystems, habitats, topography
Size and diversity of marine training areas	Near shore, off shore, shallow water, beach environment
Susceptability to climate-change-related effects	Forecast changes are likely to have a measurable effect on habitats and ecosystems
Environmental onstraints on use	contamination, encroachment, noise, time-of-day limitations, flight altitudes
Current environmental issues	Endangered species, invasive species, dust generation, air quality, noise
Installation and tenant missions and operations	
Types and diversity of missions	combined arms
Operational tempo	activities supporting current operations
Types and diversity of equipment used	missiles, sensors, communications
Types and diversity of training activities and exercises conducted	units (aircraft, ground units, artillery, missiles, amphibious, surface vessels, submarines)
Activities that could be affected by elements of climate change	Outdoor physical activities, aircraft operations, use of training lands and waters, use of sensors
Susceptability to climate-change-related effects	temperatures, sea level rise, severity and frequency of storms, air quality
DoD and mission transformation	Changes in weapon systems, new missions, changes in force structure and equipment
Regional Dependencies	
Size and type of communities	Population, economics, demographics
Degree of integration with DoD installation	Utilities, energy
Local and regional climate-change-related issues	Water supply, air quality, water quality, energy demand
Susceptability to climate-change-related effects	Forecast changes are likely to have a measurable effect on regional and local issues
Availability of data	Data are available for analysis
DoD or Federal strategic or policy issues	
DoD transformation	On-going transformation of missions and weapon systems, changes in strategic threats
Mission changes as a result of climate change	Humanitarian, ocean access, counter-terrorism, operational tempo
Installation interest and cooperation	
Installation engagement	Command and installation personnel will cooperate with study
Potential complicating factors	
BRAC	Installation is not scheduled for closing
Installation realignment	Installation is not scheduled for realignment or realignment is nearly complete
DoD transformation	Changes in strategies, weapons, and training and exercise requirements are not well defined

Appendix D Overview Survey of Research by Federal Civilian Agencies Related to Climate Change Impact Assessments and Adaptation Planning

D.1 Climate Change Modeling of Temperature and Precipitation

D.1.1 Department of Energy

The Office of Biological & Environmental Research also has a Climate Change Research Division on climate modeling that awards grants through two components. One is the core Climate Change Prediction Program, which is focused on developing and evaluating climate models, mainly via the Community Climate System Model (CCSM), a general circulation coupled climate model based at the National Center for Atmospheric Research (NCAR). CCSM is jointly supported by the NSF and DOE. A grant announcement on climate modeling closed at the end of the year 2008 (http://www.sc.doe.gov/grants/LAB09_06.html). The other component is the climate applications of the DOE Office of Science's Scientific Discovery through the Advanced Computing (SciDAC) Program (http://www.scidac.gov/), which supports the development of advanced numerical methods needed to undertake climate simulation on high-performance computing platforms.

The DOE Environmental Sciences Division supports the Program for Climate Model Diagnosis and Intercomparison (PCMDI, http://www-pcmdi.llnl.gov/), which maintains the Lawrence Livermore National Laboratory (LLNL)-Reclamation-Santa Clara University downscaled climate projections derived from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset archive. The downscaled data is stored and served at the LLNL Green Data Oasis: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/.

Also part of DOE's climate modeling program is the Climate, Ocean and Sea Ice Modeling Project (COSIM, http://climate.lanl.gov/), which handles the ocean and sea-ice components of the CCSM. More information on COSIM is provided under Oak Ridge National Laboratory in the section on *Regional-Scale Projections of Extreme Weather Events*. ORNL, home of the Cray XT5 "Jaguar" and other supercomputers, focuses on computational data science and geographical visualization tools for policy makers. NOAA will be providing $215 million to Oak Ridge National Laboratory over the next five years to support climate research.

D.1.2 Oak Ridge National Laboratory

Research supported by Oak Ridge specializes in regional scale climate models, including hydrology, and modeling climate extremes using computational data sciences. Approaches include:

- High-resolution processes within general circulation models as well as feedback to model development based on comparisons of simulations with observations)
- The development of methodologies for geographic data integration and management
- Knowledge discovery from sensor data and geospatial-temporal uncertainty quantification
- High performance analytics based on extreme value theory
- Nonlinear data sciences to develop predictive insights based on a combination of observations and climate model simulations

As mentioned above, ORNL is home to a suite of supercomputers, and is receiving $215 million from NOAA over the next five years to support climate research.

D.1.3 National Science Foundation

The National Science Foundation sponsors climate modeling research that aims to provide information about future climate on decadal and shorter time scales and at higher regional resolution. Climate scientists supported by NSF are using peta-scale computing, developing new techniques to initialize the key long-memory components of the climate system (the ocean and land surface), and developing multi-model ensemble methods for climate forecasting. NSF is also supporting research into the accurate representation of clouds in climate models. It established a new NSF Science and Technology Center, Colorado State University's Center for Multi-scale Modeling of Atmospheric Processes (CMMAP) to improve the representation of clouds in climate models. The Center is using the "multi-scale modeling framework" to embed their cloud model, which deals with the relatively small spatial scale of clouds, into a broader climate model that deals with larger scales. With this "model-within-a model" approach, the simulated physical processes occurring on different scales can interact with one another, increasing the sophistication and accuracy of the combined model.

Jointly with the National Center for Atmospheric Research and NOAA, NSF is funding HIPPO (HIAPER Pole-to-Pole Observations of Greenhouse Gases) to measure more than 30 greenhouse gases, including water vapor, ozone, and black carbon around the world at different latitudes (pole to pole) and altitudes (between 1,000 feet and 47,000 feet), and during different seasons. The monitoring is done from NSF's Gulfstream V aircraft using analytical instrumentation developed by NOAA. The flights began in January 2009 and will continue through 2011.

D.2 Hydrologic Climate Change Modeling

D.2.1 Department of Interior, U.S. Geological Survey Office of Surface Water

Under the USGS National Research Program, the Global Change Hydrology Program supports research on continental hydrology using general circulation and downscaled climate models (http://water.usgs.gov/osw/programs/globalchange.html and http://water.usgs.gov/nrp/proj.bib/peterson.html). Relevant to assessing climate change impacts, the research predicts regional streamflow by modeling seasonal variations in streamflow in relation to atmospheric circulation. It also examines the linkage between atmospheric circulation, snowpack accumulation and glacier mass balance, relevant for forecasting spring and summer water supply in the western United States and for flood forecasting. The program supports research on the physical and chemical variability in riverine and estuarine environments in relation to large-scale atmospheric and oceanic conditions, in order to discriminate between natural from human-induced effects. It also helps document the long-term behavior of hydrologic systems in response to past climatic variations and changes by studying past behavior tens, hundreds, and thousands of years ago. Related to this work is the Continental Water, Climate, and Earth-System Dynamics program, a collaborative research effort of USGS with NOAA's Geophysical Fluid Dynamics Laboratory (http://www.gfdl.noaa.gov/chris-milly/).

D.2.2 U.S. Geological Survey Earth Surface Processes

Under the category of Earth Surface Processes, USGS supports research on the physical, biogeochemical and hydrologic processes as they relate to climate change in the arid southwest (http://geochange.er.usgs.gov/poster/interactions.html). Those areas of the program relating to impacts assessment are:

- The interaction of physical and biologic processes critical for ecosystem functions.
- The interrelations among climate, vegetation, and eolian processes (sand or rock material carried by the wind) in soil fertility, invasion of exotic species, hydrology, and surface stability in deserts.
- The causes and timing of changes in alluvial environments (rivers, streams, hill slopes), such as flooding, the cutting and filling of arroyos, and sediment discharge.
- How future climatic variations will affect the Southwestern land surface (in terms of flooding, landslides, erosion, sand-dune activity, dust-storm frequency).

D.2.3 U.S. Geological Survey Ground Water Research Program

The purpose of the USGS Ground Water Research Program is to provide quantitative assessments of groundwater availability in areas where groundwater flow systems are stressed. The assessments explore the effect of climate variability on regional water budgets, evaluates the adequacy of data networks to assess impacts at a regional scale, and document the impacts of human activities on water levels, groundwater storage, and discharge to streams and other surface-water bodies. They draw upon quantitative work previously conducted by other USGS programs, including the Regional Aquifer-System Analysis Program, information from other DOI Bureaus (including the Bureau of Reclamation, National Parks Service, and Bureau of Land Management), as well as other federal agencies (such as EPA and NOAA), states, Tribes, and local governments.

D.2.4 Bureau of Reclamation

BOR has developed a process to understand how climate change will affect the reliability of snow-driven forecasts of spring-summer water supply in the West, in partnership with four NOAA NWS River Forecast Centers, the USDA National Water and Climate Center, the Army Corps of Engineers (Portland District), and Bonneville Power Administration. The approach is to translate downscaled climate projections over eight western U.S. basins into runoff and snowpack projections, using hydrologic simulation models provided by the River Forecast Centers. Within these runoff and snowpack projections, the team is developing and applying water supply forecast models, and updating procedures from federal forecast producers in USDA and the River Forecast Centers. The forecast models reflect relations between fall-winter precipitation, winter snowpack and spring-summer runoff. These models will be evaluated regarding how forecast reliability changes through time within the climate projections. The results will be used to inform adaptive management planning in the West.

BOR also has a new Basin Study Program that will better define options for future water management of Western river basins where climate change, record drought, population increases and environmental needs have heightened competition for scarce water supplies. The Basin Study will incorporate the latest science, engineering technology, climate models and innovative approaches to water management. The program provides 50% of total costs for the studies to state, local and tribal partners.

D.3 Estimates of Sea Level Rise

D.3.1 Department of Energy, Los Alamos National Laboratory

The LANL Climate, Ocean and Sea Ice Modeling (COSIM) project is working to improve estimates of sea level rise by reducing the uncertainty associated with ice sheet dynamics, ice shelf/ocean interactions, and thermal expansion. Specific target areas of the research are listed below:

- develop models of ice sheet behavior;
- model the melting of ice shelves (the floating extensions of ice sheets); and
- improve modeling of ocean steric sea level rise and our understanding of the full thermal structure of the ocean, including an improved understanding of critical processes in the transfer and mixing of heat.

In this and all related COSIM work, emphasis will be placed on the HYPOP ocean circulation model.

D.3.2 National Science Foundation

NSF-supported researchers are part of the international Polar Earth Observatory Network (POLENET, www.polenet.org) project, a consortium involving researchers from 28 nations who conduct fieldwork to improve the collection of geophysical data around the poles. In the south, researchers are constructing a network of GPS and seismic stations in West Antarctica to understand how the mass of the West Antarctic ice sheet changes over time. The information will be used to predict sea-level rise accompanying global warming and to interpret climate change records. In January 2008 NSF dedicated the permanent NSF Amundsen-Scott South Pole Antarctic Research Station. In the Arctic, another NSF-funded research team is constructing a network of 38 GPS stations in Greenland to collect better data on ice sheets. NSF is also supporting the Center for Remote Sensing of Ice Sheets (CReSIS) to improve on current estimates of sea level rise resulting from global warming. The Center is consortium of six U.S. universities and international collaborators from Denmark, Norway, Australia, the United Kingdom, and Iceland. The team uses satellite-based sensing of the earth with Unmanned Aerial Vehicle and traditional airborne-based radar, along with seismic and other measurements with data products, modeling, and analysis.

D.4 Uncertainty in Climate Change Projections

D.4.1 Department of Energy, Oak Ridge National Laboratory

A key item on ORNL’s research agenda is to improve climate process models by developing a comprehensive treatment for assessing and reducing climate change uncertainties, especially with regard to extreme events and impacts at local to regional scales.

D.5 Climate System Tipping Points Causing Abrupt Change

D.5.1 Department of Energy, Lawrence Berkeley National Laboratory

The IMPACTS project (Investigation of the Magnitudes and Probabilities of Abrupt Climate TransitionS, http://esd.lbl.gov/research/projects/abrupt_climate_change/impacts/) assesses the potential for triggering several types of abrupt climate change during the 21st century, focused on decadal scale time scales rather than centennial. The mechanisms being examined are:

- Ice shelf dynamics, evaluating marine ice sheet instability.

- Boreal and Arctic ecosystems: studying phenomena such as vegetation and snow cover shifts that amplify radiative forcing.
- Rapid destabilization of methane hydrates (or clathrates) in Arctic Ocean sediments.
- Potential abrupt transition to mega-drought conditions in North America, including the role of biosphere-atmosphere feedbacks.

IMPACTS is managed by the Lawrence Berkeley National Laboratory Earth Sciences Division in collaboration with the Argonne National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory and Pacific Northwest National Laboratory.

D.5.2 Los Alamos National Laboratory

LANL research is focused on high-latitudes, where among other areas they are investigating the impact of high-latitude changes on the stability of the ocean circulation. The goal is to improve our understanding of how high-latitude fresh water inputs might impact the thresholds of stability for the thermohaline circulation under climate change. The research will focus on:

- High resolution ocean and coupled model simulations and hosing experiments
- Development of an implicit ocean model based on POP/HYPOP ocean circulation models
- Analyzing parameter continuation and stability to solve for stable and unstable equilibria as a function of a given parameter
- Improving parameter sensitivity to estimate directly the sensitivity of the Meridional Overturning Circulation (MOC) to small changes in the forcing and other parameters in the model

LANL is also supporting research on modeling ocean and ice biogeochemistry at high latitudes, in order to better understand how ecosystems near the ice edge will respond to changes in sea ice extent, altering the carbon and sulfur exchange and perhaps accelerating ice melt. Of particular interest are the methane clathrates in shallow Arctic sediment deposits, because biogeochemical processing will determine how much methane released from sediments will reach the ocean surface and how much will be converted to carbon dioxide. This area of research will evaluate the likelihood of large-scale methane release from methane clathrates by modeling biogeochemistry in the Los Alamos Sea Ice Model (CICE). The models will be enhanced to account for missing methane processes and deep ocean ecosystems and coupled with sediment models, and a bubble/plume model will be added to HYPOP.

D.6 The Impact of Climate Change on Storm Activity

D.6.1 National Science Foundation

NSF has been and will continue to support research into the effects of climate change on the formation and intensity of tropical cyclones and other types of storms, including thunderstorms. One recent project was the development of the URSAT dataset which contains 170,000 storm-centered satellite observations

in over 2,000 storms worldwide. With support from NSF, researchers at the University of Wisconsin and NOAA’s National Climatic Data Center have developed the first global homogeneous record of tropical cyclone intensity estimates from 1978-2006. Another study at Purdue University used global and high-resolution regional climate models to examine large-scale meteorological conditions that foster severe weather formation in the United States. Based on distributions of temperature, moisture, and winds that influence severe convective storms, the study concluded that there likely will be an increase in the number of days in which severe thunderstorms occur by late in the century.

D.6.2 Department of Energy, Los Alamos National Laboratory

One of the target research areas of the Climate, Ocean and Sea Ice Modeling (COSIM) project is improved mapping of the coastline using variable resolution unstructured grids in their high resolution modeling, and coupling the results with regional flood and inundation models.

D.6.3 Department of Interior, U.S. Geological Survey

The National Assessment of Coastal Vulnerability to Sea-Level Rise, implemented by the Woods Hole Field Center (Figures D-1 and D-2) (http://woodshole.er.usgs.gov/project-pages/cvi/) uses a coastal vulnerability index (CVI) as a measure of the relative risk that physical changes will occur as sea level rises based on tidal range, wave height, coastal slope, shoreline change, geomorphology, and the historical rate of relative sea-level rise. The index serves as an indicator of overall vulnerability to sea level rise by combining susceptibility and capacity to adapt, factoring a coastal system's natural ability to adapt to changing environmental conditions with its susceptibility to higher water levels. It is calculated as follows:

$$CVI = \sqrt{((a*b*c*d*e*f)/6)}$$

where,

- a = geomorphology
- b = coastal slope
- c = relative sea-level rise rate
- d = shoreline erosion/accretion rate
- e = mean tide range
- f = mean wave height

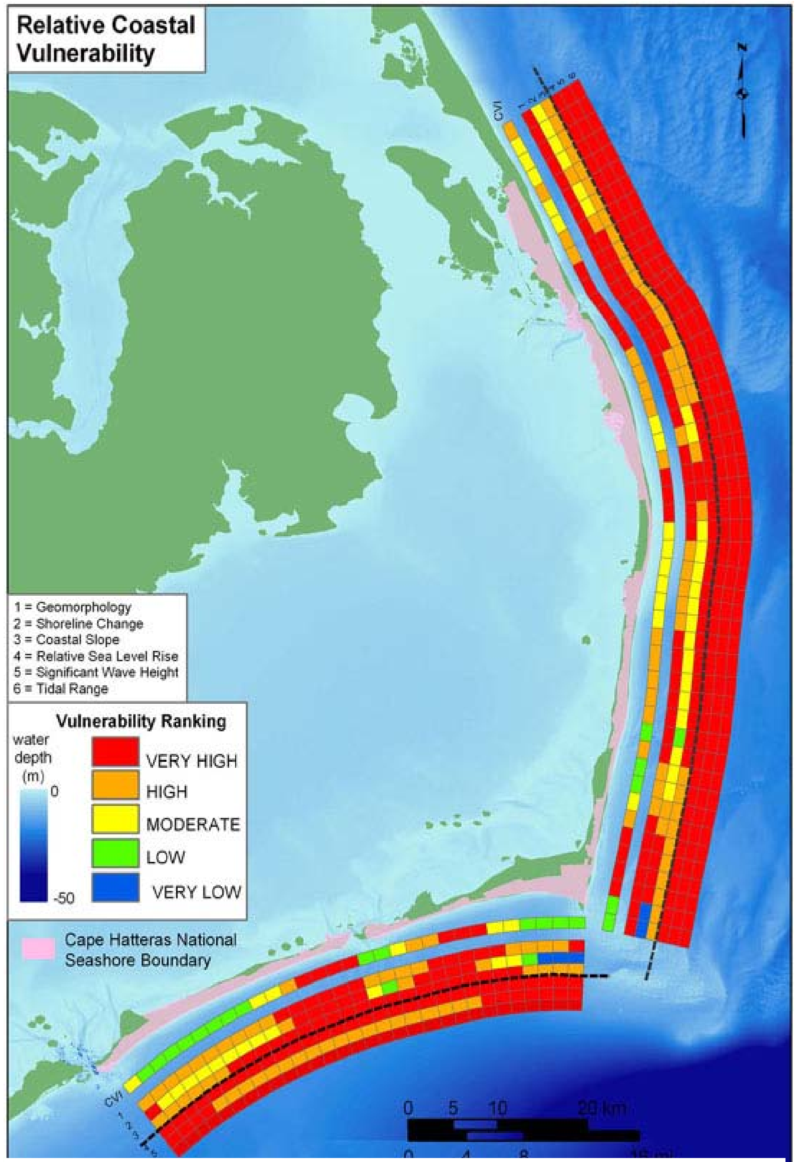

Figure D-1. USGS coastal vulnerability index for Cape Hatteras.

Figure D-2. USGS Coastal Vulnerability Index for the Gulf of Mexico.

Indices have been calculated for the Atlantic, Gulf and Pacific Coasts (see figure for Gulf Coast), and is now being applied to all National Parks in the U.S. and its territories, in partnership with the National Park Service (http://woodshole.er.usgs.gov/project-pages/nps-cvi/); see for example the figure for Cape Hatteras.

D.6.4 USGS Biological Resources Discipline

Part of the USGS Global Change Research program is geared towards improving our understanding of the natural processes controlling wetland elevation and the potential for submergence of our coastal wetland habitats.[1] The 2004-2008 round of research grants supported two studies of the vulnerability of coastal wetland systems to global change, one on the brackish wetland community and one on Great Lakes Wetlands.

D.6.5 Environmental Protection Agency

EPA funded a grant for implementation from 2008 through 2011 titled "Beach Grass Invasions and Coastal Flood Protection: Forecasting the Effects of Climate Change on Coastal Vulnerability."

D.6.6 National Science Foundation

NSF is funding research into the ability of mangrove ecosystems to adapt to sea level rise, in terms of the mangrove forest's natural function and ability to maintain soil elevations relative to sea-level rise by vertically building sediment deposits with trapped organic matter. NSF is also supporting research at the Florida Coastal Everglades Long-Term Ecological Research Program to assess the complex interactions of Everglades restoration, land-use changes driven by a growing human population, and water supply issues. Restoration may temporarily slow the landward encroachment of sea-level rise and enhance recharge of the critical Biscayne Aquifer,

[1] http://geochange.er.usgs.gov/poster/coastecosystems.html;
http://biology.usgs.gov/ecosystems/global_change/GCcycle_0408.html.

supplies more than 6 million people with freshwater and is in danger of seawater intrusion. Over the long-term, however, consequences of sea level rise confound the benefits of restoration, and this longer-term horizon is the one being examined by the new program. Another NSF program, the Dynamics of Coupled Human and Natural Systems program, is investigating the future of developed coastal barrier islands with respect to sea level rise.

D.7 Ecosystem Management

D.7.1 Department of Agriculture

USDA is conducting research in many climate change adaptation areas relating to agriculture and ecosystem management, including the following:

- The projected impact of pests (e.g., gypsy moths and bark beetles), weeds and diseases
- Projecting risks faced by different ecosystems types (such as forests and grasslands) and seed sources
- Developing climate adaptation approaches for forests
- Assessing the ability of feedbacks between ecosystem and the climate to either mitigate or intensify climate change impacts
- Downscaling global circulation models

D.7.2 USDA National Forest Service

Most of USDA's ecosystem management work relating to climate change is being conducted under the U.S. Forest Service (FS). The underlying impetus for its research is the sustainable management of 191 million acres of national forests and grasslands, defined as these ecosystems retaining the ability to provide the suite of products and services they currently provide. See Figure D-3. The FS identifies about $27 million of its research funding devoted to climate change, with about a third of that relating to adaptation.

The FS management regions collaborate closely on climate change research with FS research stations and other land management groups that facilitate the sharing of advice, information, and approaches to adapting ecosystems to climate change. One form of this collaboration is working groups, for example:

- Region 8 (southern US) created a "Climate Change Working Group" to monitor effects of disturbances related to climate change.
- Region 6 (Pacific Northwest: OR and WA) partnered with the Pacific Northwest Research Station to form a "Climate Change Strategy Group" to manage forests to better adapt to climate change.
- Region 9 (Northern Midwest and Northeast) formed a "Climate Change Catapult Team" to develop a Climate Change Action Plan, including adaptation actions.

Another example of collaborative research is the Climate Change Resource Center (CCRC, http://www.fs.fed.us/ccrc/), a website with decision support materials for forest managers created by three western research stations. The intent is to create a toolkit to guide forest managers in adapting western National Forests to climate change, for example by selecting appropriate genetic stock for healthy growth under future climate conditions. The web site includes the development of downscaled climate changes projections using local information on ecosystem feedback for the southern U.S. and data from the regional global change models provided by the Community Climate System Model of the National Center for Atmospheric Research. This work ties in with that of the Center for Forest Disturbance Science, which is building an integrated regional climate modeling framework to provide high-resolution climate change scenarios for the southern U.S., and to assess the ability of feedbacks between ecosystems and climate change to mitigate or intensify climate change impacts. This research involves using the NCAR regional climate model to downscale global-scale projections to a resolution of 10 km. Also for the South, the Southern Research Station is developing a forest plan template aimed at integrating climate change adaptation into the National Forest Plan Revision process, and it is establishing a Climate Change Pilot Forest to better understand climate change options in forest planning.

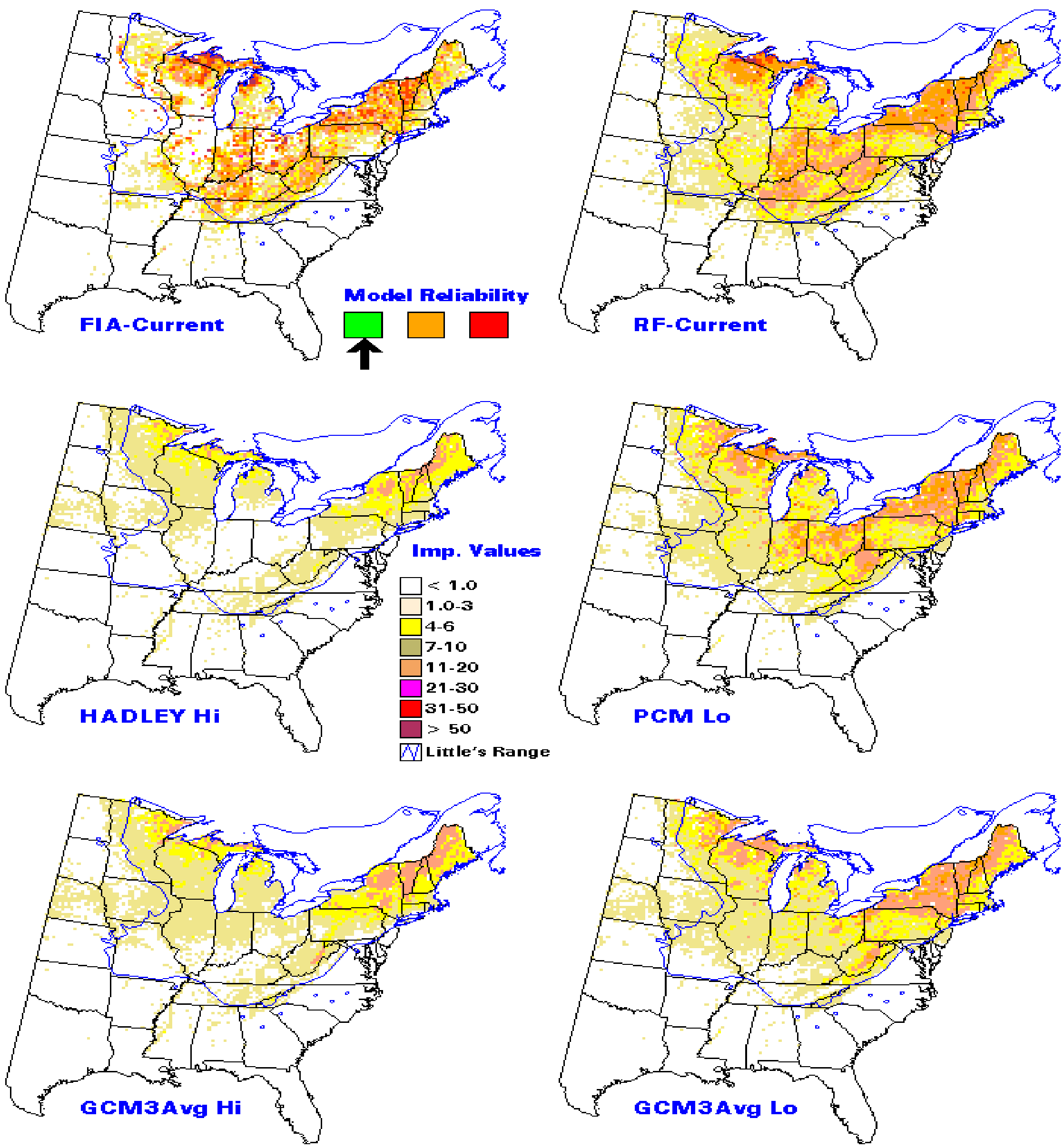

Figure D-3. Example of projections provided by the U.S. Forest Service Climate Change Tree Atlas, showing the increased range of the sugar maple projected under different GHG emission scenarios

In Alaska, FS scientists from the Pacific Northwest Research Station (covering AK, OR and WA) are synthesizing options for ecosystem adaptation by modeling effects of climate change on wildlife habitats and species there. The Eastern Forest Environmental Threat Assessment Center (EFETAC, http://www.forestthreats.org/) and Western Wildland Environmental Threat Assessment Center (WWETAC, http://www.fs.fed.us/wwetac/ and http://www.fs.fed.us/wwetac/projects.html) were created by the FS to help protect American forest and wild lands from emerging threats, including climate change. Among the many projects conducted by these programs relating to climate change, WWETAC is in the process of developing multi-criteria decision support systems capable of generating a set of National Environmental Threat Assessment Maps (NETAMs, http://www.fs.fed.us/wwetac/projects/brewer.html) to map the future risks to western forests and grasslands from multiple stresses, including future climate change, wildfire, invasive species, pest outbreaks and land use change. WWETAC is also working with Oregon State University to assess the genetic and silvicultural options for adaptation of Pacific Northwest forests, including the development of "climate smart" pest models.

Future threats by pests is an active area of FS research for in the western U.S., including projections of future bark beetle outbreaks due to climate change, an assessment of the interactions between climate and tree pathogens, and an effort with the Canadian Forest Service to adapt risk assessment protocols to assess the effects of climate change on future dynamics of the gypsy moth in the Pacific Northwest. Another active area of research in the west is the development of case studies and pilot projects to test adaptation strategies.

The Northern Research Station, with covers 20 states in about the northeast quadrant of the country, has created a Climate Change Tree Atlas (http://www.nrs.fs.fed.us/atlas/tree/tree_atlas.html) and Climate Change Bird Atlas (http://www.nrs.fs.fed.us/atlas/bird/index.html). The atlases show current and potential future distributions in the eastern half of the U.S. under high and low emissions scenarios (A1fi and B1) and three climate models with high, medium and low sensitivity to climate (Hadley CM3, GFDL2.1, and PCM, respectively). An example of some of the output from the tree atlas is shown in the figure. The Northern Research Station also partnered with Region 9 to create a Climate Change Model Forest in central Wisconsin to test and demonstrate climate change adaptation approaches.

Region 1 (Northern Region: ID, MT, ND and SD) is working with the Rocky Mountain Research Station to prepare four climate change case studies on national forests in North Dakota, Montana and Idaho, and the Pacific Northwest Research Station is developing replicate case studies of adaptation management options in the Olympic and Okanogan-Wenatchee-Colville National Forests and Olympic National Park. At nine locations throughout the Pacific Northwest, the potential impacts of climate change on seed sources are being investigated.

This overview provides a sense of the many areas of research supported by the Forest Service relating to ecosystem management. More details are provided in the e-supplement to the GAO's recent report on Federal Efforts to Adapt to a Changing Climate (see pp. 15 to 26).[2]

[2] "Climate Change Adaptation: Information On Selected Federal Efforts To Adapt To A Changing Climate (GAO-10-114SP), October 7, 2009), an E-supplement to GAO report GAO-10-113, "Climate Change Adaptation: Strategic Federal Planning Could Help Government Officials Make More Informed Decisions".

D.7.3 USDA Agricultural Research Service

The Agricultural Research Service has identified five research areas they intend to pursue to help agriculture adapt to climate change:

- *Understanding the responses of agricultural systems to anticipated climate change.* This research will be geared to understanding of how climate change affects crop and forage quality through an improved understanding of how the carbon cycle, nitrogen cycle and soil-plant atmosphere systems will respond to elevated levels of CO_2, ozone, precipitation, and temperature. It will also examine management approaches to improve water efficiency at elevated CO_2.
- *Understanding the impact of anticipated climate change on endemic and exotic pests, weeds and diseases.* Risk assessment tools will be developed for predicting the effects of anticipated change on endemic and invasive weeds, pests, and diseases in different agricultural systems. Anticipated production losses for U.S. agricultural systems will be estimated and agricultural and pest management techniques will be examined for their suitability in an altered climate. The work will also endeavor to identity likely future invasive species and their attributes, including their statistical and spatial modeling of their ranges.
- *Evaluating germplasm and identify genetic variation that will respond positively to climate change.* This area of research is aimed at identifying genes in current crop cultivars, as well as wild relatives and ancestral germplasm of crop species, that will be tolerant to future challenges such as reduced availability of water and elevated ozone. The research will also seek to develop molecular markers for crop CO_2 responsiveness, ozone tolerance, and temperature limitations.
- *Evaluating and adapting agronomic management to climate change.* The development of management strategies that increase the resilience of crops to temperature and precipitation extremes and control agronomic weeds occurring with climate change across a wide range of cropping systems, soils, and climate. An improved understanding of the carbon sequestration capacity of different crops under elevated CO_2 levels, and the underlying mechanism for residue decomposition.
- *Developing scalable methodologies for assessing potential impacts and adaptation of agriculture to climate change.* An analysis of what has been projected on the responses of major crops to climate change, and the development of models to better predict the responses of crops. The creation of a national database for characterizing crop responses and a high resolution local database of case studies that characterize projected responses to climate change.

D.7.4 USDA Natural Resources Conservation Service

The Natural Resources Conservation Service (NRCS) is promoting mechanisms for adapting to climate change by supporting the development of the knowledge and tools to guide decision making on how to prepare for environmental stresses such as drought, changes in disease or pest prevalence, and floods, and to improve the resilience of natural and managed ecosystems to climate change. Specific advances NRCS is working towards include:

- Identifying geographic areas and land management systems most vulnerable to climate change, in terms of soil types, landscapes, and ecosystems
- Evaluating strategies for increasing ecosystem resilience.

- Developing an inventory of Dynamic Soil Properties to evaluate soil resilience and changes in various ecological systems under different land use and management strategies
- Designing conservation technology and systems to assist producers with adapting to climate change, including databases of projected climate changes and improving SNOwpack TELemetry (SNOTEL, http://www.wcc.nrcs.usda.gov/snow/) and the Soil Climate and Analysis Network (SCAN) sites to improve farming and ranching production under changing climate scenarios.

D.7.5 USDA Cooperative State Research, Education, and Extension Service

The Cooperative State Research, Education, and Extension Service (CSREES) is the main vehicle through which USDA provides its extramural research funding, through competitive grants, formula grants, and non-competitive grants and agreements. Relating to assessing climate change impacts and adaption planning for ecosystems, CSREES funded a grant that is studying Land Cover and Land Use Change (LCLUC) in the Upper Mississippi River Basin under current climate conditions and under various climate change scenarios in this region for the next 5 to 50 years. The study is examining the implications of the conservation policy and the potential feedbacks between LCLUC and climate to assess the environmental and economic impacts of LCLUC. Another program supported by CSREES is *AgroClimate* (http://agroclimate.org), a decision support system being developed to reduce agricultural risks caused by climate variability. However, it does not attempt to provide information relating to future climate change, but rather is a tool to show rainfall and temperature statistics from the past under different conditions, such as El Niño and La Niña. It is operated by the Southeast Climate Consortium, a consortium of research and extension faculty from seven academic institutions from Florida, Georgia, Alabama, and North Carolina.

D.7.6 Department of Energy, Office of Biological & Environmental Research Climate and Environmental Sciences Division

The DOE Office of Biological & Environmental Research Climate and Environmental Sciences Division (http://www.sc.doe.gov/ober/CCRD_top.html) sponsors the National Institute for Climatic Change Research (NICCR, http://niccr.nau.edu). NICCR supports research into the impacts of climate change on terrestrial ecosystems, those not adjacent to an ocean as well as coastal (adjacent to an ocean, including barrier islands). An RFP was issued for work to begin April 2010 to study the “potential effects of contemporary climatic change on the structure and functioning of important U.S. terrestrial ecosystems, or that would answer important questions about possible feedbacks from terrestrial ecosystems to changes in climate or atmospheric composition. NICCR is managed and coordinated through five Regional Centers that handle inland ecosystems and a Coastal Center for coastal ecosystems, each of which is hosted by a university.

D.7.7 Department of Interior, U.S. Geological Survey

The USGS Biological Resources Discipline funds grants that research stresses to ecosystems managed by the Department of Interior, including those caused by climate change. In its latest round of Global Change Research projects (2004-2008), the Biological Resources Discipline supported twelve research projects investigating the impact of climate change on arctic, coastal, forest, high altitude and wetland ecosystems, as well as biological carbon sequestration and invasive species (http://biology.usgs.gov/ecosystems/global_change/GCcycle_0408.html).

D.7.8 National Park Service

The National Park Service's Vital Signs Program is the steward of ecosystem and natural resource data in the parks, including long-term legacy monitoring data, natural resources utilized, and new data inventories. These records are important in helping to discern effects of climate change.

D.7.9 Bureau of Land Management

BLM is responsible for managing much of the federal land affected by invasive species and wild fire, and conducts research into these issues on an ongoing basis, including their relation to climate change. Much of the research is geared to providing the information needed to support decision-making, such as mapping annual plant invasions (ground, aerial, satellite; developing native plant restoration protocols; and mapping historic fires to understand causes. BLM is also developing adaptation plans to restoring native plant communities and reducing fire frequency, and taking action in anticipation of local changes due to a changing climate such as natural habitat restoration. They are also working with commercial seed producers to grow native seed for restoration. The end goals of the adaptation plan are to reduce invasive species, reduce severity of wildfire, assure the necessary presence of pollinators, and pre-adapt susceptible lands to climate change.

D.7.10 Environmental Protection Agency

The Great Lakes Restoration Initiative is a $475 million proposal by the Obama administration to clean up the Great Lakes. It would be managed by EPA and 15 federal partners as a climate change adaptation effort to address the stresses to which the Great Lakes will be subjected as the climate changes. Special attention would be paid to invasive species, which is already a serious issue for the Lakes, and to habitat restoration.

EPA also funded the following grants, for implementation from 2008 through 2011, under the solicitation titled: "Ecological Impacts from the Interactions of Climate Change, Land Use Change and Invasive Species":

- Predicting Relative Risk of Invasion by the Eurasian Saltcedar and New Zealand Mud Snail in River Networks Under Different Scenarios of Climate Change and Dam Operations in the Western United States
- Integrating Future Climate Change and Riparian Land-Use to Forecast the Effects of Stream Warming on Species Invasions and Their Impacts on Native Salmonids
- Understanding the Role of Climate Change and Land Use Modifications in Facilitating Pathogen Invasions and Declines Of Ectotherms
- Elevated Temperature and Land Use Flood Frequency Alteration Effects on Rates of Invasive and Native Species Interactions in Freshwater Floodplain Wetlands
- Ecological Impacts from the Interactions of Climate Change, Land Use Change and Invasive Species

D.7.11 National Science Foundation

NSF supports the development of next-generation climate models that better represent the dynamics of biosphere, carbon, water and nutrient cycles, and more tightly integrate biophysical and social sciences. Their research also provides crucial information needed to validate these models, by supporting sites in long-term ecological research and centers for biological synthesis. Another area of research is adaptation phenomena and unknown dimensions of biodiversity at short time scales (within a decade), to better understand the relationships between biodiversity, ecosystem services, and human systems.

D.8 Ocean Acidification and Impacts on Marine Ecosystems

D.8.1 National Science Foundation

NSF has supported research in the past into ocean acidification by climate change and in FY 2010 its funding on Ocean Sciences will have an increased emphasis on climate change including acidification. NSF also provides significant support for research on the impacts of climate change on marine ecosystems.

D.9 Shifting Patterns for Disease Vectors

D.9.1 Center for Disease Control

CDC, in partnership with the National Center for Atmospheric Research, has a 2010 postdoctoral fellowship program in which fellows will conduct research in epidemiology, ecology, behavioral science, modeling and atmospheric science for the purpose of training climate and health scientists to address climate-related public health challenges.

D.9.2 National Science Foundation

NSF is supporting research that investigates the ecology of infectious disease and the biology of invasion by exotic species.

D.10 Engineered Infrastructure and Navigationally Significant Coastal Facilities

D.10.1 National Science Foundation

NSF has funded research in the past relating to the impacts of extreme events or climate change, such as sea level rise, on infrastructure, for example a project titled "Global Climate Change and Transportation Infrastructure: Lessons from the New York Area". Information was not found to indicate that this would be an area of focus in the future.

D.11 Resilient Electricity Supply

D.11.1 U.S. Department of Energy Office, DOE Electricity Delivery and Energy Reliability

The main USG agency funding research and development on microgrids is DOE's Office of Electricity Delivery and Energy Reliability (http://www.oe.energy.gov/), often in partnership with the California Energy Commission Public Interest Energy Research Program (http://www.energy.ca.gov/research/index.html). This support led to the development of the Consortium for Electric Reliability Technology Solutions (CERTS) microgrid technology (http://certs.lbl.gov/certs-der-micro.html), including the CERTS Microgrid Laboratory Test Bed located at the American Electric Power Company Walnut Test Facility in Columbus, OH (http://certs.aeptechlab.com/).

DOE has supported also microgrid development through avenues other than CERTS. For example it awarded a $4.2 M grant to GE Global Research to develop a microgrid energy management system. The project involved developing microgrid specifications, investigating business models, developing advanced local supervisory controls and algorithms, and demonstrating the technology at the city of Wayne, New Jersey. The National Renewable Energy Laboratory and Rocky Research were partners on the project. Another DOE-sponsored project recently completed was the simulation of a fuel-cell-powered microgrid-connected neighborhood by the University of South Alabama and its industry partner Radiance Technology Inc.

D.11.2 NASA Ames Research Center

The NASA Ames Research Center is supporting the development of microgrids via the Renewable Energy Micro Grid (REMG) test bed consisting of a tracking photovoltaic system, wind turbine, and energy storage and distribution systems. The work is being conducted in partnership with the Bio-Info-Nano Research and Development Institute (http://www.bioinfonano.org/), which is a consortium of university, government, and industrial partners located in the Advanced Studies Laboratory on the Ames campus. The Laboratory is a joint project of the University of California Santa Cruz and Ames.

D.12 Decision Support Frameworks and Tools

D.12.1 Environmental Protection Agency

The research in EPA’s Global Change Research Program “provides a strategic approach to providing the science needed to develop adaptations to climate variability.” The studies conducted under the program are used to develop “assessments and decision-support tools” and “to investigate adaptation options to improve society's ability to effectively respond to the risks and opportunities presented by global change, and to develop decision support tools for resource managers coping with a changing climate.” The program is focused specifically on air quality and water quality/aquatic ecosystems, and the resulting consequences on human health.

D.12.2 National Science Foundation

NSF is supporting a number of projects to assist decision making around climate change. One project is assessing urban adaptation planning and adaptation strategies to conserve or reuse water, manage stormwater, and reduce energy use in the face of uncertain climate change impacts. Research is also supported to translate climate change predictions and uncertainties into useful information for drought preparedness planning, and the use of renewable energy resources to adapt to climate change impacts. Another project is exploring the use of electronic systems to sense and detect environmental changes. In addition, NSF established five Decision Making Under Uncertainty Centers/Collaborative Groups (DMUU) to conduct research on climate-related decisions under conditions of uncertainty. There are three research centers, located at Arizona State, Carnegie-Mellon, and Columbia universities, and two collaborative groups (at the University of Colorado at Boulder and the Rand Corporation in Santa Monica). The Decision Center for a Desert City (DCDC) at Arizona State was established to foster better decision-making under climatic uncertainty and to apply this principle to water-management decisions in the urbanizing desert of Central Arizona. One tool it developed was WaterSim, a systems-dynamics model that simulates water supply and demand in Central Arizona under various climate, usage, and policy scenarios. WaterSim is available online at http://watersim.asu.edu/. At Carnegie Mellon University’s Climate Decision Making Center, researchers focus on how to deal with “irreducible uncertainties”—the limits of our understanding of climate change and its impacts—to develop methods for policymakers to rank ecological risks. At Columbia University, the Center for Research on Environmental Decisions studies individual and group decision-making under climate uncertainty in order to improve risk communication and increase the use of scientific information in decision-making.

Appendix E GAO – Climate Change Adaptation

Noblis general findings are consistent with the results of a 2009 Government Accountability Office (GAO) study, in which GAO surveyed a broad range of federal, state, and local officials on climate change adaptation activities and the challenges these officials faced in determining climate change adaption needs and actions.[1] GAO obtained summaries of current and planned adaptation-related efforts and received responses from 187 federal, state, and local officials to a questionnaire on challenges associated with adaption efforts.

GAO found that the lack of site-specific information limits the ability of officials to respond to the effects of climate change (GAO Table 3 reproduced below). Almost 75 percent of the 187 responders stated that translating available climate information into effects at the local level and lack of availability of climate information at a relevant scale were considered very or extremely challenging issues. Respondents also stated that developing processes and tools to help officials access, interpret, and apply available climate information was very important, as was the need for state and local climate change impact and vulnerability assessments (GAO Table 6 reproduced below). GAO also found that the lack of clear processes and responsibilities regarding climate change assessment and adaptation was an issue with officials (GAO Table 4 reproduced below).

Table 3: Percentage of Challenges Related to Information Rated as Very or Extremely Challenging

How challenging are each of the following for officials when considering climate change adaptation efforts?	Total responses[a]	Percentage who rated as very or extremely challenging[b]
Justifying the current costs of adaptation efforts for potentially less certain future benefits	179	79.3
Size and complexity of *future* climate change impacts	180	76.7
Translating available climate information (e.g., projected temperature, precipitation) into impacts at the local level (e.g., increased stream flow)	182	74.7
Availability of climate information at relevant scale (i.e., downscaled regional and local information)	179	74.3
Understanding the costs and benefits of adaptation efforts	180	70
Lack of information about thresholds (i.e., limits beyond which recovery is impossible or difficult)	175	64.6
Making management and policy decisions with uncertainty about future effects of climate change	184	64.1
Lack of baseline monitoring data to enable evaluation of adaptation actions (i.e., inability to detect change)	181	62.4
Lack of certainty about the timing of climate change impacts	180	57.2
Accessibility and usability of available information on climate impacts and adaptation	182	53.3
Size and complexity of *current* climate change impacts	179	48.6

Source: GAO.

[1] US Government Accountability Office. Climate Change Adaptation – Strategic Federal Planning Could Help Government Officials Make More Informed Decisions. GAO-10-113, October 2009.

Table 6: Percentage of Potential Federal Government Actions Related to Information Rated as Very or Extremely Useful

How useful, if at all, would each of the following federal government actions be for officials in efforts to adapt to a changing climate?	Total responses[a]	Percentage who rated as very or extremely useful[b]
Development of *state and local* climate change impact and vulnerability assessments	183	80.3
Identification and sharing of best practices	157[c]	80.3
Development of processes and tools to help officials access, interpret, and apply available climate information	185	80.0
Development of *regional* climate change impact and vulnerability assessments	182	77.5
Creation of a federal service to consolidate and deliver climate information to decision makers to inform adaptation efforts	176	60.8
Development of an interactive stakeholder forum for information sharing	184	56.5

Source: GAO.

Table 4: Percentage of Challenges Related to the Structure and Operation of the Federal Government Rated as Very or Extremely Challenging

How challenging are each of the following for officials when considering climate change adaptation efforts?	Total responses[a]	Percentage who rated as very or extremely challenging[b]
Lack of clear roles and responsibilities for addressing adaptation across all levels of government (i.e., adaptation is everyone's problem but nobody's direct responsibility)	178	69.7
The authority and capability to adapt is spread among many federal agencies (i.e., institutional fragmentation)	176	58
Lack of federal guidance or policies on how to make decisions related to adaptation	176	52.3
Existing federal policies, programs, or practices that hinder adaptation efforts	150	42.7
Federal statutory, regulatory, or other legal constraints on adaptation efforts	152	36.2

Source: GAO.